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Research on the control system of APF for micro grid

Xifeng Xie^{1,*}, Yuqiang Luo¹, Jianglin Zuo¹, Chunxiang Ling¹

¹Guangxi Hydraulic and Electric Polytechnic, Nanning 530023, China

*Corresponding author e-mail: 232652833@qq.com

Abstract. The power supply of micro grid is less stable than of conventional grid, and the harmonic pollution is more severe, aiming at this situation, in order to increase dynamic response performance ,and the steady-state compensation accuracy of an active power filter (APF), a new design scheme of APF applied to AC micro grid is proposed. In this scheme, $i_p - i_q$ algorithm is used to detect the harmonics, and the hysteresis control method is applied to control the compensation current, and the fuzzy adaptive PI controller is applied to maintain the DC-side voltage. An test platform using FPGA EP3C55F484C8N as the controller is established. The effectiveness and correctness of the proposed control method are verified in the simulation and experiment.

1. Introduction

The single-chip microcomputer (SCM) or Digital Signal Processing (DSP) are used as the control chip in the traditional APF control system. But computing ability of SCM is relatively weak, which cannot calculate some complex control algorithm. DSP needs frequent interruption in the data processing process, and uses the programming software to calculate complex control algorithms, which greatly cuts down the operation speed, as a result, the dynamic and static performance of APF are cut down. Field Programmable Gate Array (FPGA) has some advantages of high integration, high frequency, low power consumption, simple calculation process, short development cycle, low design cost, flexible configuration, and flexible programming, etc. FPGA can perform high-speed parallel computing by pure hardware and can handle different tasks simultaneously, which is very suitable for processing control algorithm of APF. The harmonic detection algorithm is the key technology of APF, $i_p - i_q$ algorithm uses only the voltage signal and phase signal in the process of computing, so $i_p - i_q$ algorithm is not affected by voltage waveform in the micro grid, it can accurately detect the fundamental current even on unbalanced three-phase voltage. Voltage fluctuations of the DC-side will affect the performance of APF, Voltage tracking control method is used to control DC side capacitor voltage through a PID controller. However, the conventional PID controller with the fixed PI parameters is difficult to adapt to the changing environment of micro grid. The fuzzy adaptive PI controller can adjust the integral coefficient K_{I} and proportion coefficient K_{P} online, which is very suitable for the change of micro grid. Harmonic currents are controlled by a pulse width modulation (PWM) in APF, Hysteresis current control method is widely used in PWM, which uses current instantaneous value to compare, it does not need the carrier, its dynamic performance is good, and its structure is simple.

So, a novel design scheme of APF applied to micro grid is proposed, The scheme uses FPGA EP3C55F484C8N controller to calculate algorithm, uses $i_p - i_q$ algorithm to detect harmonic currents.

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uses hysteresis current method to adjust compensation current, and uses the fuzzy adaptive PI controller to stabilize the DC-side voltage. As a result, the dynamic tracking speed and detection precision of the system is improved, the tracking deviation of the compensation current is reduced, and the distortion rate of the power supply is reduced. The validity and correctness of the design scheme are verified by Simulation and experiment

2. Another section of your paper



Figure 1 Structural schematic diagram of $i_p - i_q$ algorithm.

Structural diagram of $i_p - i_q$ algorithm is shown in Figure 1; this algorithm mainly uses a cosine circuit and a Phase Locked Loop(PLL) to produce sine and cosine signals with the same frequency and phase.

The value of i_{α} and i_{β} are obtained according to the transformation matrix C_{32} multiplying the load current:

$$\begin{bmatrix} i_{\alpha} \\ i_{\beta} \end{bmatrix} = C_{32} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$
(1),

Where $C_{32} = \frac{2}{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}$, i_{La} , i_{Lb} , i_{Lc} are the load currents.

The value of i_p and i_q are obtained according to the transformation matrix C multiplying by i_{α} and i_{β} :

$$\begin{bmatrix} i_p \\ i_q \end{bmatrix} = C \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$
(2)
where, $C = \begin{bmatrix} \sin \omega t & -\cos \omega t \\ -\cos \omega t & -\sin \omega t \end{bmatrix}$

The AC term of i_p and i_q is filtered by Low-Pass Filter, and the DC term i_{pd} and i_{qd} are attained. The deviation between the feedback voltage and the given voltage is transformed into the signal Δi_{dc} in PID controller, and Δi_{dc} is added to the DC term i_{pd} of, and i_{af} , i_{bf} , i_{cf} are attained through reversed transformation CC_{32} . IOP Conf. Series: Journal of Physics: Conf. Series **1176** (2019) 062037 doi:10.1088/1742-6596/1176/6/062037

$$\begin{bmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \end{bmatrix} = C_{32}^T C^T \begin{bmatrix} i_{pd} + \Delta i_{dc} \\ i_{qd} \end{bmatrix}$$
(3)

ultimately the instruction current signal i_{Ra} , i_{Rb} and i_{Rc} are calculated.

$$\begin{bmatrix} i_{Ra} \\ i_{Rb} \\ i_{Rc} \end{bmatrix} = \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} - \begin{bmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \end{bmatrix}$$
(4)

2.2. control strategy of the DC-side voltage ^[5-6]Voltage tracking control method is adopted to stabilized the DC-side voltage to a given value, which regulates the DC-side capacitor voltage through PID controller, The parameter setting of PI controller directly determines the performance of the system, but the harmonics in the micro grid are nonlinear and real-time change, The conventional PI controller with the fixed PI parameter is difficult to adapt to the changing environment of micro grid. To further increase the dynamic response speed of the controller, the fuzzy adaptive PI controller is used to replace the conventional PI controller. Figure 2 is Structural schematic diagram of fuzzy adaptive PI control.



Figure 2 Structural schematic diagram of fuzzy adaptive PI control

In Figure 2, U_{dcr} is the given DC-side voltage, U_{dcs} is the actual DC-side voltage , ΔU is Voltage deviation, $d\Delta U/dt$ is deviation rate, α_e and α_c are respectively the quantization factor of ΔU and $d\Delta U/dt$, K_I^* and K_p^* are respectively the initial integral coefficient value K_I and proportion coefficient value K_p .

The fuzzy control principle is used to find the relation between the two parameters (K_1 and K_p) and $(d\Delta V/dt \text{ and } \Delta V)$.

Firstly, Voltage deviation ΔU and deviation rate $d\Delta U/dt$ are calculated.

$$\begin{cases} \Delta U = U_{dcr} - U_{dcs} \\ d\Delta U(k)/dt = \Delta U(k) - \Delta U(k-1) \\ \Delta U(k) = \Delta U(k-1) \end{cases}$$
(5)

And then ΔU and $d\Delta U/dt$ are fuzzed, ΔK_P and ΔK_I are regulated by Mamdani fuzzy inference method.

 $\begin{cases} \Delta K_P = f_1(\Delta U, d\Delta U/dt) \\ \Delta K_I = f_2(\Delta U, d\Delta U/dt) \end{cases}$ (6)

Next, the proportional and integral coefficients of the PI controller are modified.

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$$\begin{cases} K_p = K_p^* + \Delta K_p \\ K_I = K_I^* + \Delta K_I \end{cases}$$
(7)

Finally, the adjustment signal Δi_p is calculated through PI controller.

$$\Delta i_p = k_p \Delta U + k_i \int_0^t \Delta U dt \qquad (8)$$

2.3. control strategy of the DC-side voltage

^[7-9]Structural schematic diagram of the Hysteresis current control method is shown in Figure 3,The difference Δi_c between the instruction current i_c^* and the actual compensation current i_c is sent to the hysteresis comparator, PWM signal is generated according to the result of Δi_c comparing with the comparator ring width H, The on-off of the inverter switch is controlled by PWM signal through the drive circuit. Thus the compensation current i_c is effectively controlled.



Figure 3 Structural schematic diagram of the Hysteresis current control method

In Figure 3, the following characteristics of the compensation current are closely related to the ring width H of the hysteresis comparator; When the inequality $\Delta i_c > H$ is met, the switch function S is set to 1, IGBT switch tube is operated and i_c is increased; When the inequality $\Delta i_c < -H$ is met, the switch function S is set to 0, IGBT switch tube is operated and i_c is reduced.

3. Simulation and experimental analysis

3.1. Simulation

According to the above theoretical analysis, a simulation system is established in MATLAB, which is composed of APF, Nonlinear load and three-phase AC power. the effective value of AC voltage is 220 V, the frequency is 50Hz, the DC-side capacitor is 6400uF, AC-link inductance is 2mH, resistance is 0.5 Ohm, and the output voltage of the energy storage system is 800V.

Figure 4 shows waveforms of system current and voltage with and without APF, The change of the load current is quickly followed by the compensation system, and the current waveform is improved greatly after APF used in the 0.03s time. After 0.02s, the system is stable in the new equilibrium state, and the dynamic characteristic is excellent.

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Figure 4 waveforms of system current and voltage with and without APF Figures 5 and Figure 6 show respectively THD of system current without APF and with APF. in Figures 5, we can see that the percent of THD is 28.18%, harmonic is 5/7/11/13/17/19 order harmonic, respectively. percent of 5/7/11/13/17/19 order harmonic is 25.63%/16.23%/5.28%/4.33%/3.06%/1.40%. In Figure 6, we can see that the percent of THD is 2.87% .



APF

Figure 6 THD of system current with APF

3.2. experimental analysis

The experimental device is composed of a inverter control system, a typical nonlinear load and control system. FPGA EP3C55F484C8N is the main control chip, the core control algorithm is programmed by using HDL Verilog language. The module includes ADC driver module, PI controller module, low pass filter module, PLL module, three-phase inverse transform and coordinate transformation module, voltage loop and current loop control system module, hysteresis control module and SPWM modulation module etc.

The parameters of the experimental platform are set as follows: frequency is 50Hz,AC voltage is 220 V, non-linear load resistance is 20 Ohm, non-linear load inductance is 2mH, energy storage capacitor is 0.33 mF, output inductor is 0.2mH, input filter inductor is 1mH, the switching frequency of the Intelligent Power Module (IPM) is 10KHz, the dead time is 0.0025 ms. The initial proportional and integral coefficient of the fuzzy PI controller is respectively 5.5 and 0.15, the factor of Deviation quantization and Deviation rate quantization is respectively equal to 0.075 and 0.05.

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compensation

In Figure 7, Curve 1 is DC-side voltage, curve 2 is source current, curve 3 is load current, curve 4 is APF output current, As is shown that the waveform of source current with APF almost come near to sinusoidal.

Figures 8 and Figure 9 are respectively THD of source current without APF and with APF. In Figure 8,we can see that the percent of THD is 25.1%, The main harmonic components are 3,5,7,11 and 13 order harmonic. In Figure 9,we can see that the percent of THD is 2.3%, The experimental results show that the effect of harmonic compensation is very good.

4. Conclusion

The power supply of micro grid is less stable than of conventional grid, and the harmonic pollution is more severe. The traditional APF control system has the problems of complex structure, low filtering precision and poor real-time compensation. Aiming at this situation, A new design scheme of APF applied to AC micro grid is proposed. In this scheme, SCM and DSP are abandoned and FPGA is used. $i_p - i_q$ method is adopted to detect the harmonics, the fuzzy adaptive PI controller is applied to control the DC-side voltage, Hysteresis current control method is applied to control the compensation current, PWM is used to operate IGBT switch tube. As a result, the compensation accuracy and real-time performance of APF are greatly improved.

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