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Study on improved Ip-iq APF control algorithm and its application in micro grid

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Abstract. In order to enhance the tracking velocity and accuracy of harmonic detection by ip-iq algorithm, a novel ip-iq control algorithm based on the Instantaneous reactive power theory is presented,the improved algorithm adds the lead correction link to adjust the zero point of the detection system, the Fuzzy Self-Tuning Adaptive PI control is introduced to dynamically adjust the DC-link Voltage, which meets the requirement of the harmonic compensation of the micro grid. Simulation and experimental results verify the proposed method is feasible and effective in micro grid.

1. Introduction

As an effective supplement to the large power grid, micro grid plays an important role in power system. However, the use of a large amount of distributed power supply, inverter and non-linear power electronic devices in micro grid leads to appear harmonic pollution, which affect the Power quality. Harmonic current separation from the current signal acquisition is the premise and key of harmonic control. As is known to all, fast Fourier transform algorithm, neural network algorithm, HHT algorithm, wavelet transform algorithm, d-q algorithm and ip-iq algorithm are often used to detect harmonic currents, and each has different advantages and disadvantages[1-2].

Considering the unstable output voltage of micro power, unbalanced three-phase voltage and vulnerable to environmental impact in micro grid, and ip-iq algorithm is not affected by the voltage waveform, which can accurately detect the fundamental current component even in three-phase voltage distortion [3-4], So, ip-iq algorithm is applied in this design. However, Current detection is delayed because of the use of low pass filter in ip-iq algorithm, which reduce the dynamic and static performance of the system.

So, in order to further improve the speed and accuracy of current detection, a novel ip-iq algorithm based on the Instantaneous reactive power theory is presented, which improves the dynamic response speed of the system by adding the lead correction link to adjust the zero point of the detection system. the Fuzzy adaptive PI controller is used to replace the conventional PI controller, Charge and discharge of the DC-link capacitor are adjusted flexibly by adjusting the parameters of PI controller online, thus the DC-link voltage is quickly adjusted to a given value, which improves the precision of harmonic detection system. Simulation and experimental results support the validity and accuracy this design.

2. Ip-Iq algorithm

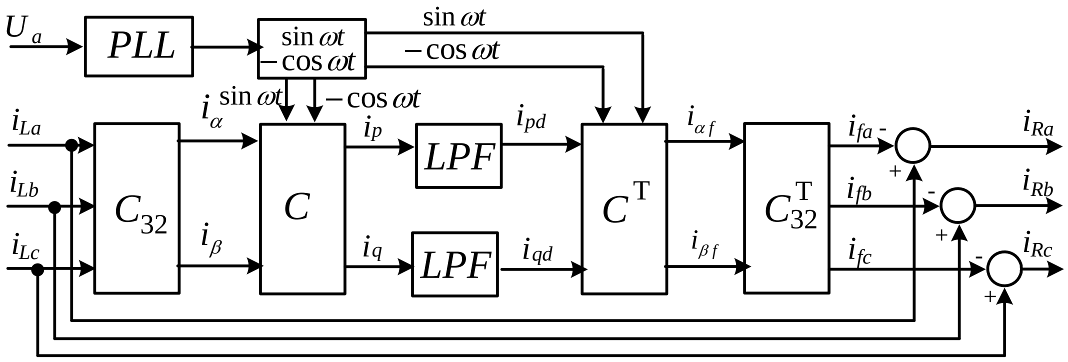

Figure 1. Structural schematic diagram of ip-iq algorithm

Figure 1 shows Structural schematic diagram of ip-iq algorithm, this method mainly applies a Phase Locked Loop (PLL) and a cosine circuit to generate a sine and a cosine signal, which have a phase voltage u_a phase with the same frequency. And then the values of i_α and i_β are calculated according to transformation C_{32}:

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

Where, i_{La} , i_{Lb} , i_{Lc} are the load currents, The expressions of C_{32} is following.

$$C_{32} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}$$

The values of i_p and i_q are calculate d according to transformation C :

$$\begin{bmatrix} i_p \\ i_q \end{bmatrix} = C \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{2}$$

The expressions of C is following.

$$C = \begin{bmatrix} \sin\omega t & -\cos\omega t \\ -\cos\omega t & -\sin\omega t \end{bmatrix} \tag{3}$$

We can attain dc term i_{pd} and i_{qd} via a low-Pass filter, and Get i_{af} , i_{bf} , i_{cf} through reversed transformation :

$$\begin{bmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \end{bmatrix} = C_{32}^{T} C^{T} \begin{bmatrix} i_{pd} \\ i_{qd} \end{bmatrix} \tag{4}$$

Ultimately the instruction current signal, i_{Ra} , i_{Rb} and i_{Rc} are calculated:

$$\begin{bmatrix} i_{Ra} \\ i_{Rb} \\ i_{Rc} \end{bmatrix} = \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} - \begin{bmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \end{bmatrix} \tag{5}$$

Current detection is delayed due to the use of low pass filter in ip-iq algorithm, which can reduce the dynamic response performance of harmonic detection; The DC-link voltage appears to fluctuate due to voltage distortion and voltage fluctuation in micro grid. As a result, the detection effect of the algorithm is affected.

3. Improved Ip-iq algorithm

3.1. Series lead correction network

[5-6] In order to further Increase the tracking speed of harmonic detection, Advance correction are used, the delay is compensated by adding lead correction link after LPF. Lead-correction principle diagram used in ip-iq algorithm is shown in Figure 3; the central box in the middle of the Figure is the leading correction link. LPF uses the two order Butterworth low pass filter, sampling frequency is 10 kHz, and cut-off frequency is 30 Hz. The transfer function is as follows:

$$G_0(s) = \frac{{\omega_0}^2}{s^2 + 2\xi\omega_0 s + {\omega_0}^2} \tag{6}$$

Where, ω_0 is the cut-off angle frequency of the filter, $\omega_0 = 2\pi f_0$; ξ is the damping ratio, Considering the fast response of the filter , $\xi = 0.707$.

The transfer function for each phase current detection is as follows:

$$H_k(s) = \frac{s^2 + 2\xi\omega_0 s}{s^2 + 2\xi\omega_0 s + {\omega_0}^2}, \quad k = a,b,c \tag{7}$$

Where, $-\omega_0 + j\omega_0\sqrt{1-\xi^2}$ and $-\omega_0 - j\omega_0\sqrt{1-\xi^2}$ are pole points of each phase transfer function, Take frequency equal to 30HZ as an example ,-133.3+j133.3 and -133.3-j133.3 are pole points, 0 and -266 are zero points. Detection response speed is reduced because -266 is away from the origin.

So, in order to increase the detection response speed, the transfer function of the system is adjusted by adding a lead correction link after LPF, Lead correction link function is as follows:

$$G_c(s) = \frac{k(\tau s + 1)}{(T_0 s + 1)} \tag{8}$$

In the above formula, the choice of T_0 and τ should be satisfied the inequality $T_0 \ll \tau$, and the value τ can be chosen according to the zero point, Usually T_0 is equal to 0.01τ .Take ω_0 equal to 30HZ for example, Lead correction link function is as follows:

$$G_c(s) = 0.01 * (0.38s + 1)/(0.0038s + 1) \tag{9}$$

Pole is 266 and Zero point is -2.66 in Correction link function.
The transfer function of each phase after correction is as follows:

$$H_k(s) = \frac{s(s + 2.66)}{(s^2 + 266.4s + 3.549 \times 10000)},\ k = a, b, c \tag{10}$$

The zero points are 0 and -2.66 after adjustment, the pole points are -133.3+j133.3 and -133.3-j133.3 after adjustment. The pole remains unchanged after adjustment, while the zero shifts from 266 to 2.66, which greatly improves the dynamic response performance detection system.

3.2. *Fuzzy self-adaptive PI control*

[7-8]The stability of the DC-link voltage is the key to guarantee the harmonic current compensation; the harmonic compensation precision is reduced by the DC-link voltage fluctuation, which is caused mainly by micro power supply instability, the voltage distortion, voltage unbalance, the switching loss and resistance loss of system, and so on. Therefore, the voltage tracking control method is used to control the DC-link voltage in ip-iq algorithm, and the controlled value can quickly and accurately reach to the given value. The control of the DC-link voltage V_{dc} is shown in Figure 3, the deviation ΔV between the given values V_{ref} and the feedback value V_{dc} is converted to the signal Δi_{dc} through PID regulation.

The signal Δi_{dc} is added to active component i_{pd}, and the result is tracked in the current loop to ensure that the DC-link voltage V_{dc} is stabilized to a given value. But the harmonic current in micro grid is nonlinear and real-time, and the conventional PI controller cannot adjust the proportion and integral coefficient on line, so it is difficult to adapt to the changing environment of the micrso grid, In order to increase the dynamic response speed of the PI controller, the fuzzy adaptive PI controller is used to replace the conventional PI controller, The dynamic and static performance of the system is improved by adjusting PI parameters in real time, and the schematic diagram of the system is shown in Figure 2.

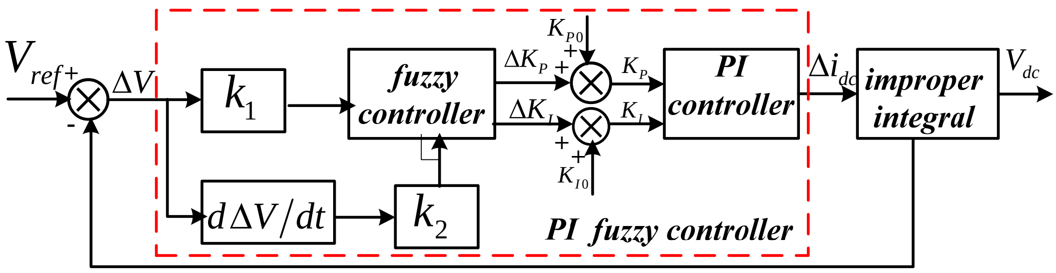

Figure 2. Structural schematic diagram of Fuzzy Self-Tuning Adaptive PI Control

In Figure 2, V_{ref} is the given DC voltage, V_{dc} is the actual DC voltage, ΔV is the voltage deviation, $d\Delta V/dt$ is the rate of deviation change, k_1 is a quantitative factor of deviation ΔU , k_2 is a quantitative factor of $d\Delta V/dt$, K_P and K_I are the actual coefficient and integral coefficient. K_{P0} And K_{I0} are respectively the initial values of K_P and, K_P , Δi_{dc} is the current regulation signal.

The structure relation of PI controller is as follows:

$$\Delta i_{dc} = k_p \Delta V(i) + k_i \sum_{i=1}^{n} \Delta V(i) ,$$

In the formula, $\Delta V(i)$ (i=1, 2... N) Is the sampling value of voltage error V.

The fuzzy control principle is used to find the fuzzy relation between the parameters (K_p and K_I) and (ΔV and $d\Delta V/dt$), the controlled object can obtain good dynamic and static performance through real-time on-line parameter (K_p and K_I) correction. In order to increase the control precision , ΔK_i and ΔK_p are properly reduced When ΔV and $d\Delta V/dt$ are smaller, In order to make the dynamic response speed quicker , the ΔK_i and ΔK_p are properly increased When ΔV and s are large.

ip-iq algorithm using DC Capacitor Voltage Control and lead-correction principle diagram is shown Figure 3.

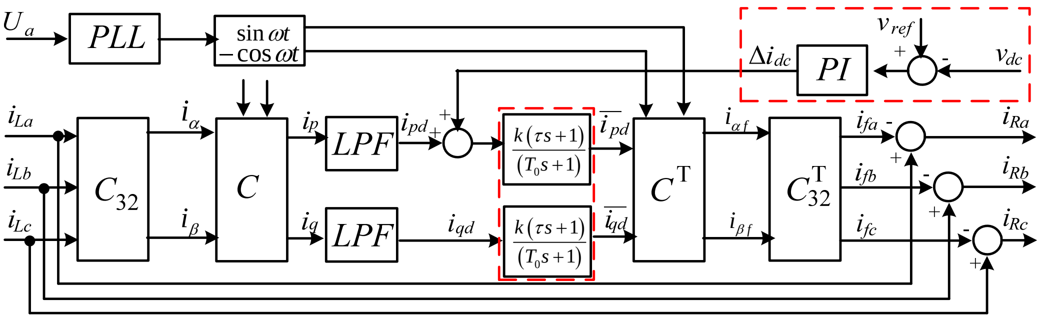

Fig 3. ip-iq algorithm using DC Capacitor Voltage Control and lead-correction principle diagram

4. Experimental results and analysis

[9-10]According to the above theoretical analysis, the micro grid model is built by Matlab/Simulink to simulate and verify the improved ip-iq algorithm. The simulation model is composed of APF, distorted load and AC micro grid. The Simulation parameters are as follows: the effective value of AC voltage is 220 V, frequency is 50Hz, DC-link capacitor is 2200uF, AC side inductance is 4mH, resistance is 0.3 ohm, and the output voltage of the energy storage system is 380V.

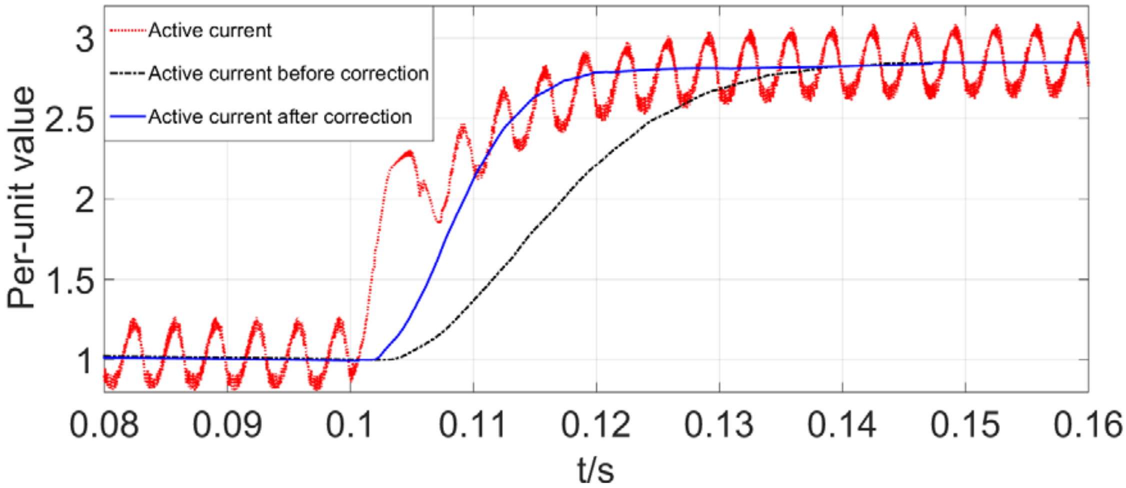

Figure 4. Waveforms of active current before and after lead-correction

waveforms of active current before and after lead-correction is shown as Figure 4, At the time of 0.1s, the external nonlinear load suddenly increases, The adjustment time of the fundamental current component is reduced from 0.04s to 0.02s after adding lead-correction, which fully indicates that the dynamic tracking speed of the detection system is improved after adding lead-correction link.

Simulation results show that the improved ip-iq algorithm has higher accuracy and faster detection speed. In order to verify the feasibility of the improved algorithm proposed in this paper, an experimental device is designed and manufactured, the main control chip uses FPGA, the current sensor uses HLA-IV sensor, the converter uses the IPM intelligent power module PM20CTM060.

In Figure 5, curve 1 is the load current, curve 2 is the harmonic compensation current, curve 3 is the supply current, and curve 4 is the DC-link capacitor voltage. It can be seen that the APF system can compensate the harmonic current of the mutation load in the 30ms, which has a good adaptability to the load mutation, and the compensation effect is very significant.

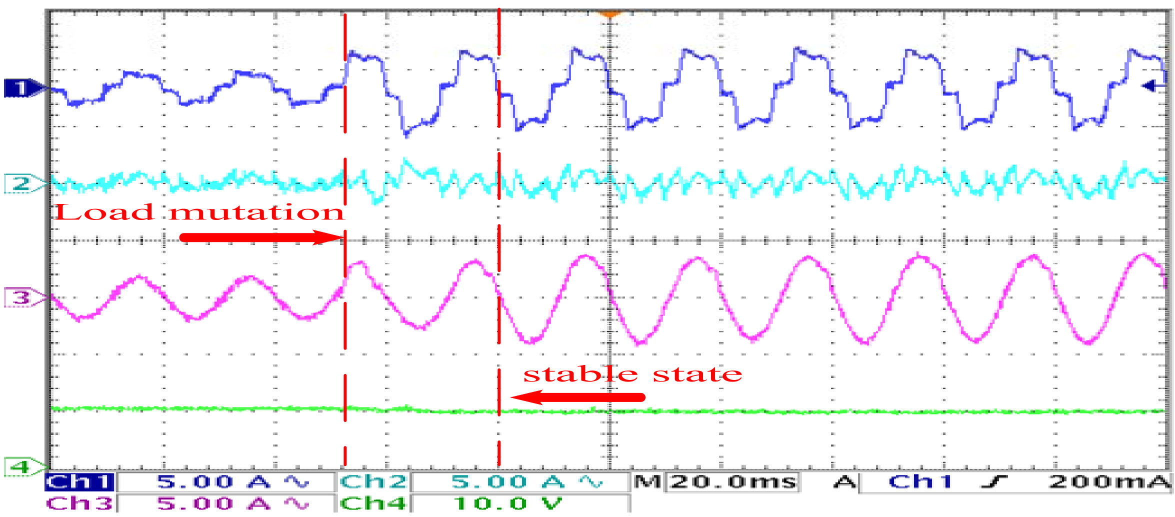

Figure 5. Dynamic response process of the system with load change

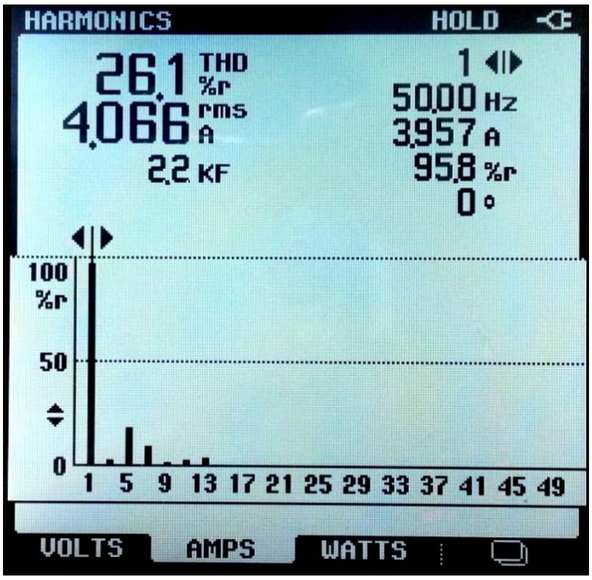

Figure 6. THD of system current without APF

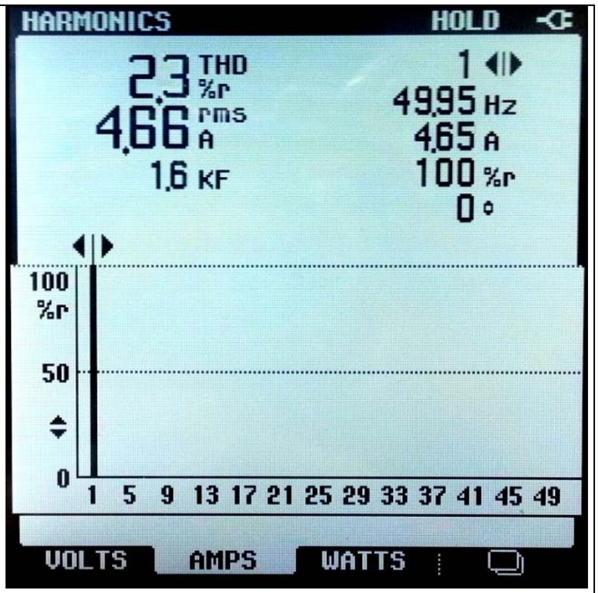

Figure 7. THD of system current with APF

THD of system current without APF is shown as Figure 6, the source current is equal to the load current without APF, as can be seen from Figure 6, and the percent of THD is 26.1%. THD of system current with APF is shown as Figure 7, it shows that THD of source current from 26.1% down to 2.3%, the harmonic component is obviously reduced, and the compensation precision is very high.

5. Conclusion

An improved ip-iq algorithm based on instantaneous reactive power theory is proposed, which introduces the series lead correction link and the fuzzy adaptive PI controller and improves the dynamic tracking speed and precision of the system. Simulation and experimental results verify that the improved ip-iq control algorithm has better accuracy and faster detection speed, which has better adaptability to the load change and can meet the requirement of harmonic detection in micro grid.

Acknowledgments

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