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Research on Current Detection Method Based on Instantaneous Reactive Power Theory

***Abstract*—This article mainly introduces the application of reactive power detection theory in reactive current and harmonic current detection. In order to detect harmonics and reactive currents quickly and accurately, this article proposes three detection methods: p-q detection method based on instantaneous reactive power theory, $i_p - i_q$ detection method and d-q decomposition detection method. Then through simulation experiments under the conditions of undistorted voltage, distorted voltage, and unbalanced three-phase voltage, these three current detection methods are introduced and analyzed, as well as their detection accuracy, speed, delay, real-time performance, and applicable occasions. The results show that the d-q decomposition detection method can perform accurate and effective detection under various conditions.**

***Index Terms*—instantaneous reactive power theory; reactive current; harmonic current**

I. Introduction

With the rapid development of power electronic technology, various power electronic devices have become more widely used in various fields, and the pollution caused by harmful currents such as harmonics and reactive currents has become more and more serious. This is a very important issue for power systems and power users, and it has caused widespread concern. The primary condition for controlling harmonics and compensating for reactive power is to be able to perform effective and accurate detection[1].

The time delay of traditional reactive current detection methods is large, and instantaneous reactive current and harmonic current cannot be obtained, thus greatly limiting their application. The proposed three-phase circuit instantaneous reactive power theory overcomes the drawbacks of traditional reactive power detection and has been widely used. Its basic idea is to apply the coordinate transformation to transform the instantaneous values of voltage and current in the three-phase circuit to the α-β two-phase intersecting coordinate system[2]. Based on the theory of instantaneous reactive power in three-phase circuits, three methods for detecting harmonics and reactive currents in three-phase circuits can be obtained: p-q method, - method, and detection methods of harmonics and reactive current based on d-q coordinate transformation.

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II. Design and Experiment

A. Description of p-q detection method

The detection process of p-q method is to calculate the active power p and reactive power q, the reactive power and active power pass the low-pass filter to filter out the high-frequency components to get the active and reactive DC components, and then after the coordinate inverse transformation can be obtained three Phase-phase current, with three-phase current and three-phase fundamental wave current difference, you can get three-phase harmonic current [3].

Set the instantaneous voltage and instantaneous current in the three-phase balanced circuit to be u_a, u_b, u_c and i_a, i_b, i_c. The steps of detecting three-phase reactive current: carry out Clarke transform with u_a, u_b, u_c respectively, to obtain u_α, u_β.

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = C_{32} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = C_{32} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

After calculation, obtain the instantaneous active power p and the instantaneous reactive power q.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} u_\alpha & u_\beta \\ u_\beta & -u_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = C_{pq} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (3)$$

Then the low pass filter obtains its dc component $\bar{p}$, $\bar{q}$, set the active dc component $\bar{p}$ =0, and after transform of C_{23}, the resulting three-phase current is the reactive current. Drawing detection flow chart shown in Fig.1.

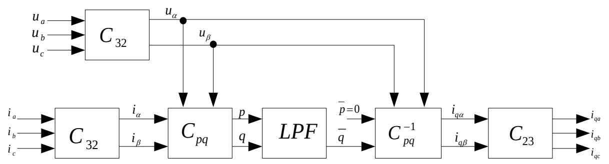


Fig.1 Detection diagram of reactive current based on the theory of p-q

When it is necessary to detect reactive and harmonic components, $\bar{q}$ should be set to 0. After inverse conversion, the fundamental active current component with the reactive power removed is subtracted from the load current, What you get is the amount of harmonics and reactive currents.

B. Description of $i_p - i_q$ detection method

In order to avoid the influence of the voltage distortion, the sine and cosine signals of the A-phase voltage of the power grid are obtained through the phase-locked loop[4].

The three-phase unbalanced current no longer contains zero-sequence components after the α-β coordinate transformation. Then after conversion the active current component and the reactive current component are obtained respectively. The resulting active current component i_p and reactive current component i_q are subjected to a low-pass filter to obtain the dc component $\overline{i_p}$ and $\overline{i_q}$ [5]:

$$\begin{bmatrix}\overline{i_p}\\ \overline{i_q}\end{bmatrix} = \sqrt{3}I_1\begin{bmatrix}\cos\varphi_1\\ -\sin\varphi_1\end{bmatrix} \tag{4}$$

The detection block diagram shown in Fig.2

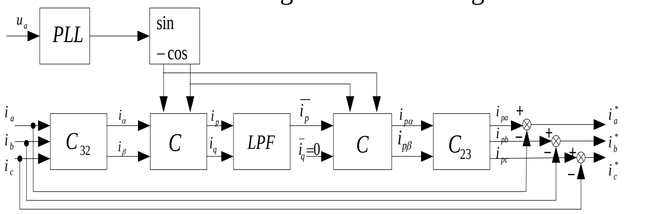


Fig.2 Detection diagram of reactive current based on the theory of $i_p - i_q$

The current resulting from the inverse transformation of $\overline{i_p}$ and $\overline{i_q}$ is the fundamental current: if $\overline{i_q}$ =0, the current resulting from the inverse transformation is the fundamental active current. Subtracting the detected current from the fundamental active current results that is the harmonic current which needs to be compensated[6].

C. Description d-q decomposition detection method

The d-q decomposition method is a transformation method for projecting voltage and current in a rotating coordinate system. Three-phase unbalanced current is transformed into two-phase synchronous rotation d, q coordinate system by positive and negative sequence rotation coordinates, and the positive and negative sequence AC currents in the original three-phase stationary abc coordinate system are converted into direct current., while the negative and positive sequence alternating currents are converted into second harmonics[7-8]. If the second harmonic can be filtered in the two phase d-q coordinate system, The d and q components of the positive and negative sequence output currents can be obtained separately[9]. In order to eliminate the second harmonic, the signal delay cancellation technology is used in this paper to separate the positive and negative sequence components.

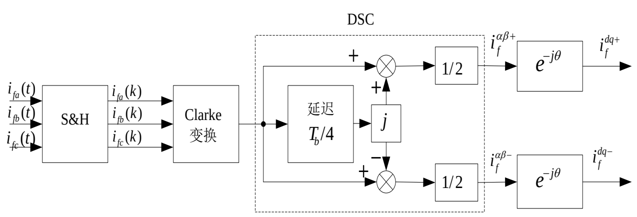


Fig.3 Delay Signal Cancellation(DSC)for separating positive and negative sequence components

Figure 3 shows the principle block diagram of separating the positive and negative sequence components of the signal delay cancellation technique. Among them, S&H is the sample and hold, and Tb is the fundamental period.

The basic working principle of Figure 3 is as follows: Assume that the capacitor current $i_{fa}(t)$, $i_{fb}(t)$, $i_{fc}(t)$ is measured by the current sensor, sampled $i_{fa}(k)$, $i_{fb}(k)$, $i_{fb}(k)$, and standardization obtained $i^*_{fa}(k)$, $i^*_{fb}(k)$, $i^*_{fc}(k)$.

$$\begin{cases} i^*_{fa}(k) = \cos(\theta(k)) \\ i^*_{fb}(k) = \cos(\theta(k) - \dfrac{2\pi}{3}) \\ i^*_{fb}(k) = \cos(\theta(k) + \dfrac{2\pi}{3}) \end{cases} \tag{5}$$

The normalized current vector is then transformed into the α-β coordinate system to obtain $i^{\alpha}_f(k)$ and $i^{\beta}_f(k)$.

$$\begin{cases} i^{\alpha *}_f(k) = i^*_{fa}(k) = \cos(\theta(k)) \\ i^{\beta *}_f(k) = \dfrac{1}{\sqrt{3}} i^*_{fa}(k) + \dfrac{2}{\sqrt{3}} i^*_{fb}(k) = \sin(\theta(k)) \end{cases} \tag{6}$$

Then use the signal delay cancellation technology to separate out the positive and negative sequence currents $i^{\alpha\beta *+}_f(k)$ and $i^{\alpha\beta *-}_f(k)$, where $i^{\alpha\beta *}_f(k) = i^{\alpha *}_f(k) + \mathrm{j}i^{\beta *}_f(k)$, f_s is the sampling frequency and f_b is the fundamental frequency of the voltage[10].

$$\begin{cases} i^{\alpha\beta *+}_f(k) = 0.5\left[i^{\alpha\beta *}_f(k) + \mathrm{j}i^{\alpha\beta *}_f(k - \dfrac{f_s}{4f_b}) \right] \\ i^{\alpha\beta *-}_f(k) = 0.5\left[i^{\alpha\beta *}_f(k) - \mathrm{j}i^{\alpha\beta *}_f(k - \dfrac{f_s}{4f_b}) \right] \end{cases} \tag{7}$$

After the Park transformation, the positive and negative sequence current components output under the two-phase synchronous rotation d-q coordinates are as follows:

$$\begin{cases} i^{\mathrm{d}+*}_f(k) = \cos\theta i^{\alpha +*}_f(k) + \sin\theta i^{\beta +*}_f(k) \\ i^{\mathrm{q}+*}_f(k) = -\sin\theta i^{\alpha +*}_f(k) + \cos\theta i^{\beta +*}_f(k) \end{cases}$$
$$\begin{cases} i^{\mathrm{d}-*}_f(k) = \cos\theta i^{\alpha -*}_f(k) + \sin\theta i^{\beta -*}_f(k) \\ i^{\mathrm{q}-*}_f(k) = -\sin\theta i^{\alpha -*}_f(k) + \cos\theta i^{\beta -*}_f(k) \end{cases} \tag{8}$$

D. Simulation of Three Detection Methods

According to the derivation analysis of the above detection methods, the above three detection methods are simulated and verified in Simulink, a simulation model is established, and analysis and comparison are performed.

The simulation module of three kinds of detection methods is built and shown in the following figures. The filter uses Butterworth as the second-order low-pass filter, and the cutoff frequency is 50HZ. The simulations were performed under conditions of undistorted voltage, distorted voltage, and unbalanced three-phase load.

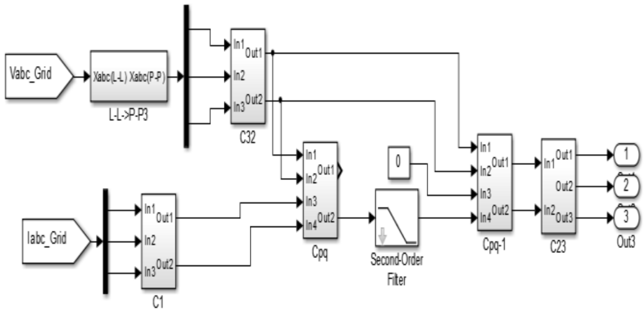


Fig.4 Simulation model of p-q detection method

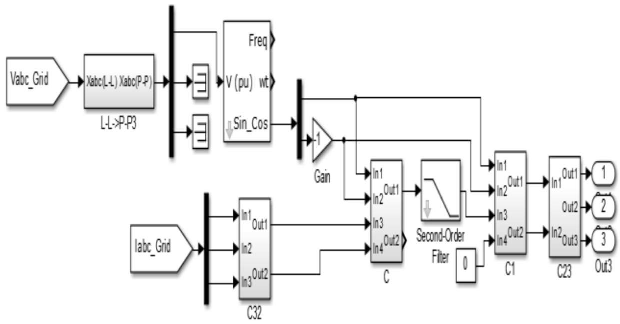


Fig.5 Simulation model of $i_p - i_q$ detection method

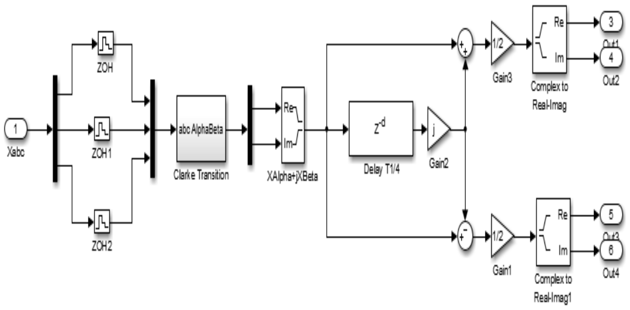


Fig.6 Simulation model of d-q detection method

The harmonic source in the power grid is the most typical of three-phase bridge rectifiers, which can be used as a simulation model. It is assumed that the fundamental voltage component of the three-phase grid voltage has a maximum value of 380 V and a frequency of 50 Hz, a non-linear load of three-phase bridges connected in series with an inductive load RL, a parameter resistance R of 50 Ω, and an inductance of 5 mH. The harmonic generation circuit is as follows:

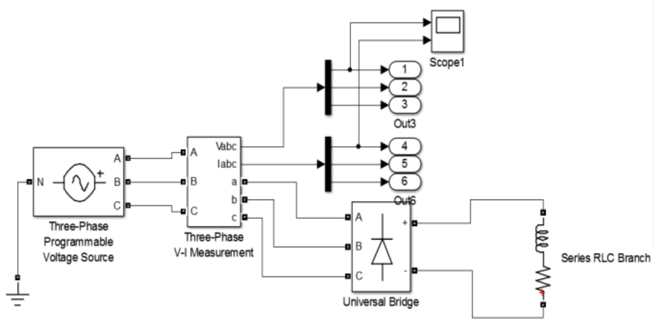


Fig.7 Simulation model of harmonic generation

E. Comparison of simulation results of the three detection methods

1. Simulation without voltage distortion

A phase circuit is taken as an example for observation. When the voltage has no distortion, the voltage and current waveforms are as shown in Fig.8 and Fig.9. It can be seen that due to the non-linearity of the load, the distortion of the

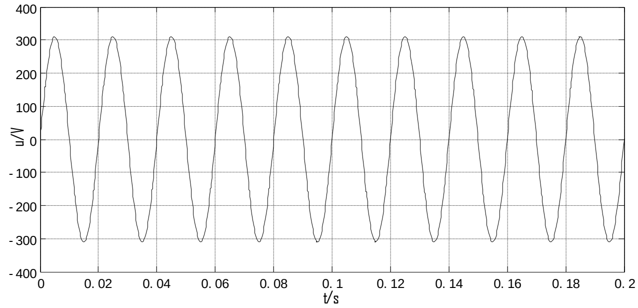


Fig.8 Voltage waveform of A-phase

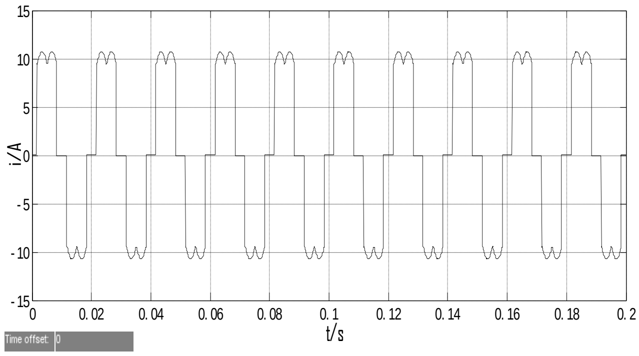
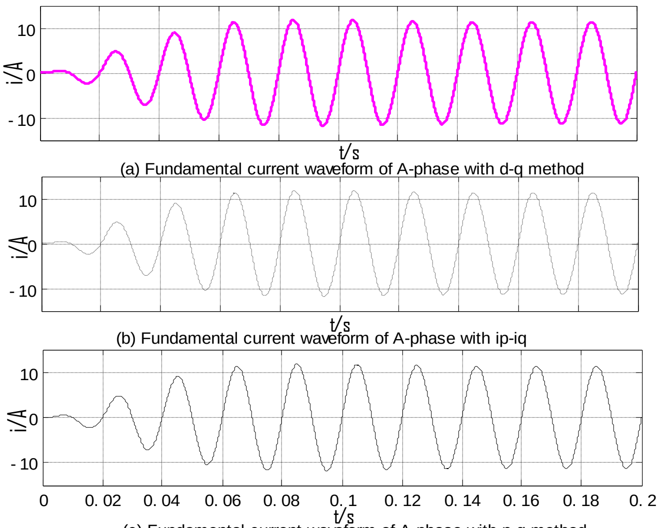


Fig.9 Distortion current waveform of A-phase

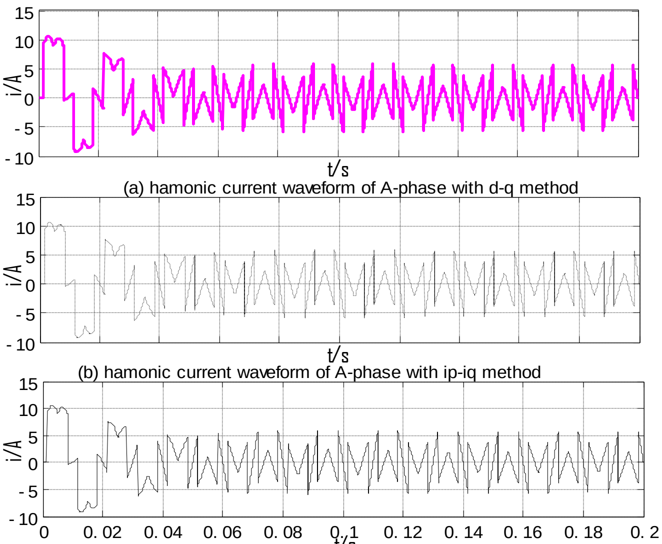


(a) Fundamental current waveform of A-phase with d-q method

(b) Fundamental current waveform of A-phase with ip-iq

(c) Fundamental current waveform of A-phase with p-q method

Fig.10 Fundamental current waveform of A-phase



(a) hamonic current waveform of A-phase with d-q method

(b) hamonic current waveform of A-phase with ip-iq method

(c) Hamonic current waveform of A-phase with p-q method

Fig.11 Harmonic current waveform of A-phase current is caused, which is no longer a sine wave but an approximate square wave.

The fundamental phase current waveforms and the harmonic waveforms of phase A detected by the p-q method, the $i_p - i_q$ method, and the d-q method are the same, as shown in Fig.10 and Fig.11.

It can be seen that in the three-phase balanced voltage without distortion, the three monitoring methods can better detect the fundamental and harmonic components.

2. Simulation with voltage distortion

When the voltage in the circuit is distorted, the distortion voltage and current are shown in Fig.12. At this time, the A-phase current fundamental component detected by the p-q method, $i_p - i_q$ method, and d-q method is shown in Fig. 13. It can be seen from the figure that when the voltage is distorted, the fundamental waveform detected by the p-q method is no longer a sine wave, and the waveforms detected by the $i_p - i_q$ and d-q methods are still sine waves in accordance with Fig.10. The waveform of the A-phase current harmonic component is shown in Figure 14. The inaccuracy of the same fundamental wave detection can be seen, and the harmonics detected by the p-q method also have large errors.

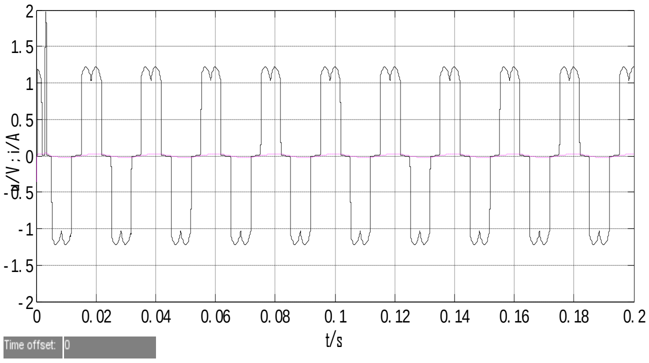


Fig.12 Distortion voltage and current waveform of A-phase

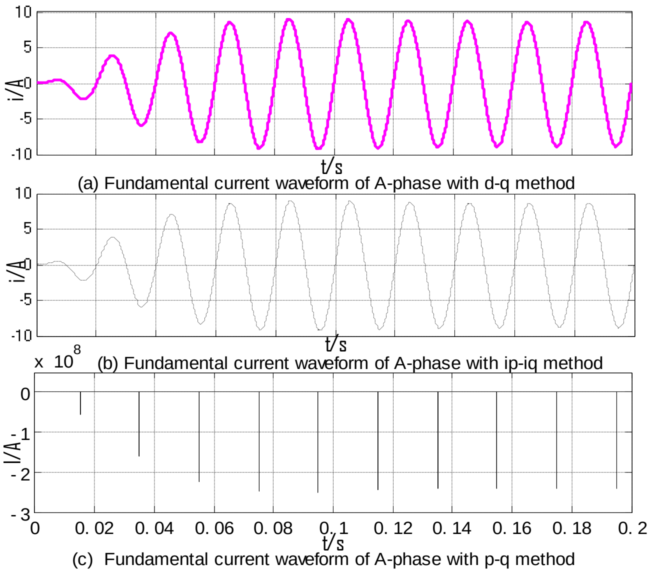


Fig.13 Fundamental current waveform of A-phase

It can be seen from the figure that under the condition of three-phase balance but the voltage is distorted, the $i_p - i_q$ method and the d-q method can better identify the fundamental and harmonic components and obtain accurate results, but there is a large error in the p-q method.

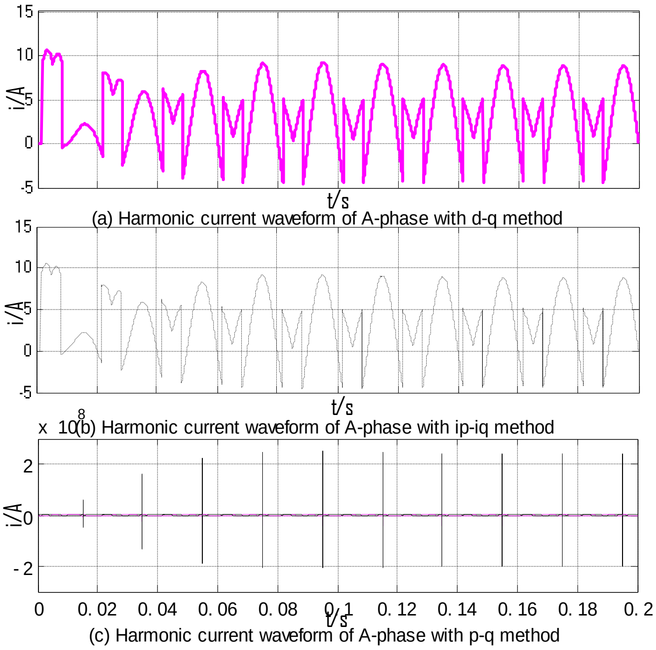


Fig.14 Harmonic current waveform of A-phase

3. Simulation under three-phase unbalance load condition

When the three-phase load is unbalanced and has harmonics, the three-phase unbalanced current is shown in Fig.15.

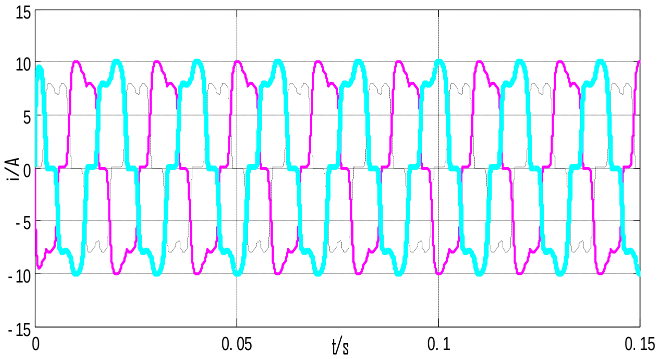


Fig.15 Three-phase unbalanced current waveform

The detection results of the p-q method, the $i_p - i_q$ method, and the d-q method are shown in Fig.16 to 20 respectively. Compared with Fig.15, it can be seen that under the condition of three-phase unbalanced and harmonics, the three-phase fundamental wave current detected by the p-q method is seriously deformed and the harmonics are not accurate; The three phase fundamental current detected by the $i_p - i_q$ method

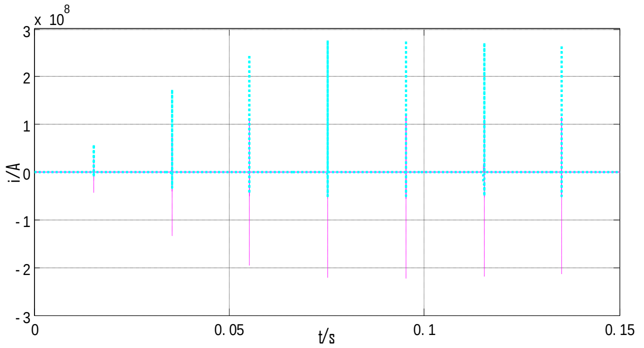


Fig.16 Fundamental current waveform of three-phase with p-q method

deviates from the actual curve and is therefore not accurate;

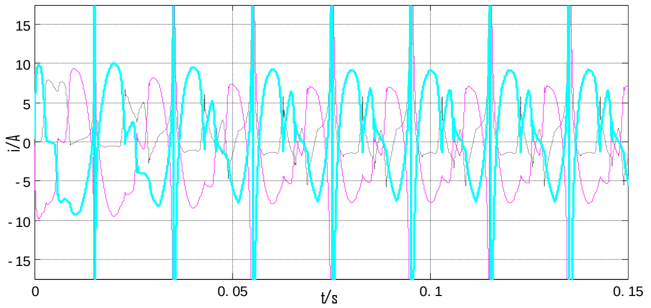


Fig.17 Harmonic current waveform of three-phase with p-q method

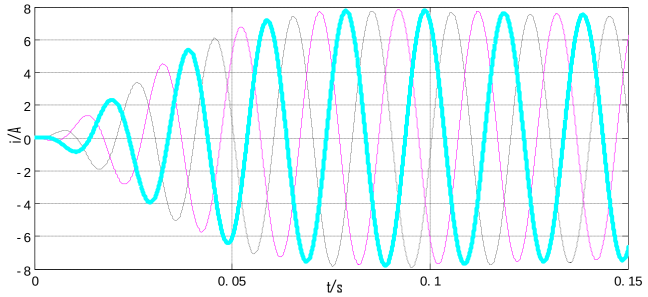


Fig.18 Fundamental current waveform of three-phase with $i_p - i_q$ method

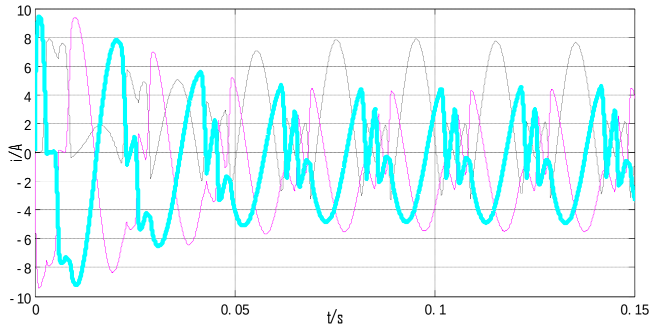


Fig.19 Harmonic current waveform of three-phase with $i_p - i_q$ method

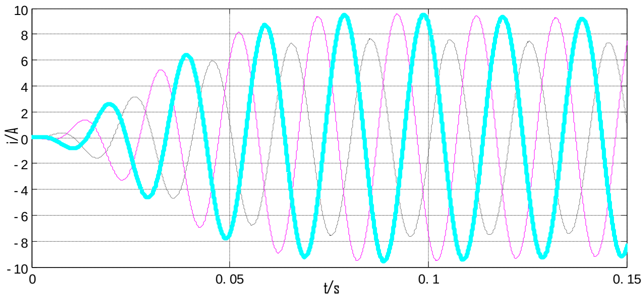


Fig.20 Fundamental current waveform of three-phase with d-q method

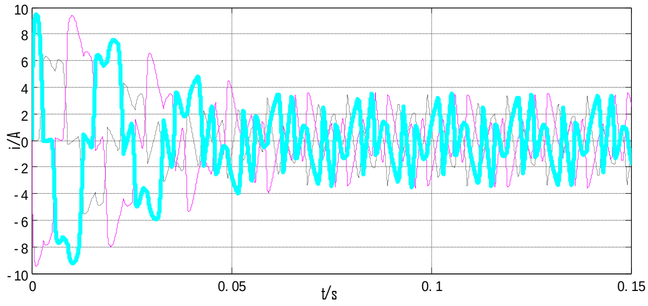


Fig.21 Harmonic current waveform of three-phase with d-q method

the d-q method can still accurately detect the three-phase fundamental current and harmonic current when the three-phase current is unbalanced.

The result of the FFT analysis of the Powergui results is shown in Fig.22 and Fig.23. The grid current contains 3, 5, 9 and 11 harmonic currents. The total current distortion THD is 27.26%. It can be seen from the fundamental wave current FFT graph detected by the d-q method that it can effectively detect the fundamental wave current, and the content of Other subharmonics are rare, and the total current distortion rate is only 0.71%.

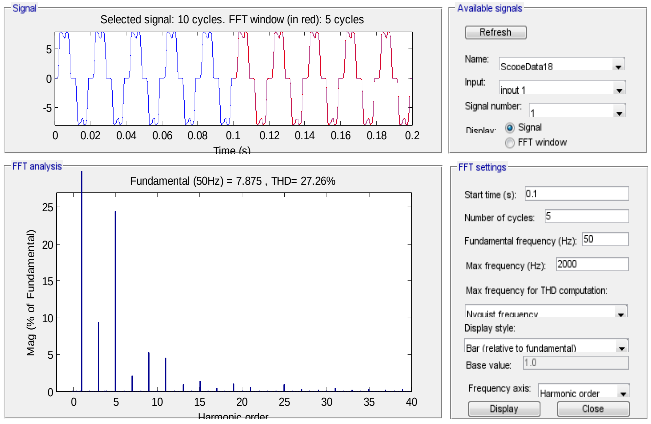


Fig.22 FFT analysis diagram of the grid current

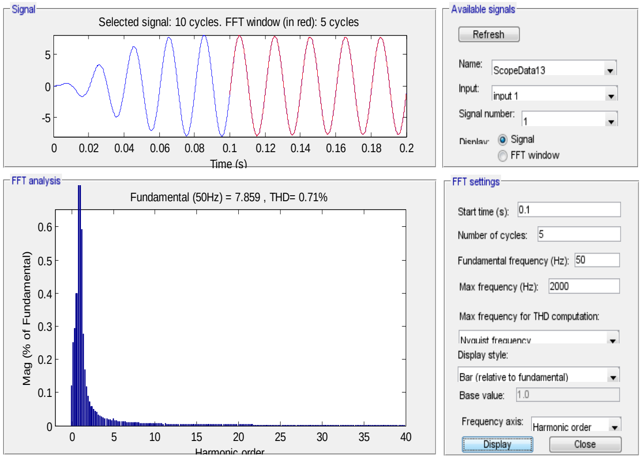


Fig.23 FFT analysis diagram of the fundamental current with d-q method

Based on the above simulation results, the following conclusions can be drawn:

a) In the case of three-phase voltage symmetrical and without distortion, the three detection methods can well detect the fundamental and harmonic currents.

b) In the case of voltage distortion, the harmonic power of the same frequency and the active power generated by the harmonic current are also dc components. In this case, the low-pass filter of the p-q algorithm does not recognize which part of the dc component comes from the fundamental wave, and which part comes from Harmonic, so it can not get accurate test results. The $i_p - i_q$ detection method uses a PLL and sine cosine generation circuit. The d-q method directly examines the fundamental wave active component. Both of these methods are independent of the voltage harmonic component, so the harmonic current can be accurately detected and the fundamental current can be well checked.

c) In the case of three-phase with asymmetrical load and higher harmonics, the $i_p - i_q$ detection method cannot be accurately verified because only the A-phase fundamental wave voltage is coupled with the load current, and the d-q method can still accurately calculate the harmonic current. And the fundamental current.

III. CONCLUSION

This article mainly introduces the theory of reactive power detection. Due to the different disadvantages and drawbacks of traditional reactive power detection methods, the instantaneous reactive power theory is commonly used. Three detection methods were constructed based on instantaneous reactive power theory: p-q detection method, $i_p - i_q$ detection method, and d-q decomposition detection method. Then the three methods were theoretically deduced and the flow charts of the testing process were drawn. Based on this, the simulation models are built, and simulation tests are performed on these three detection methods under the conditions of undistorted voltage, distorted voltage, and unbalanced three-phase voltage. Finally, the results are compared and analyzed. The results show that the d-q decomposition detection method can perform accurate and effective detection under various conditions.

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