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Detection of Three-phase Harmonic and Reactive Current Based on Instantaneous Reactive Power Theory

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Abstract—In order to detect grid harmonic and reactive current precisely and real time, this paper arrived at a method of harmonic and reactive current real-time detection applied to active power filter based on the three-phase circuit instantaneous reactive power theory. With Matlab simulation software, researches on simulation of harmonic detection means are carried out, and an analysis of the simulation result is presented. The result indicates: the harmonic detection means based on instantaneous reactive power theory can detect harmonic and reactive component in three-phase current precisely and real-time and provide reliable harmonic and reactive current for harmonic restraint and reactive power compensation. Therefore, this method can provide reliable indicator parameters for researches and development of APF and SVC.

Keywords-Instantaneous reactive power theory, harmonic current detection, simulation

I. INTRODUCTION

With the rapid development of power electronics technology , there has been a large number of non-linear loads, the resulting harmonic pollution is increasingly serious[1] [2]. To power system, no harmonic current is one of the main symbols of "green". Harmonic detection is the base of solution to all problems of harmonics. The instantaneous reactive power theory[3-5]proposed by Akagi .H in 1983 is gradually perfect after the research and has been successfully applied to the harmonic and reactive current detection. This paper introduced the harmonic and reactive current detection method based on theory of instantaneous reactive power. System simulation model is established by the Matlab/Simulink software.

II. HARMONIC AND REACTIVE CURRENT DETECTION PRINCIPLE BASED ON THE THREE-PHASE INSTANTANEOUS REACTIVE POWER THEORY[6-8]

For a three-phase power system instantaneous voltages and instantaneous currents are $\boldsymbol{e}_a, \boldsymbol{e}_b, \boldsymbol{e}_c$ and $\boldsymbol{i}_a, \boldsymbol{i}_b, \boldsymbol{i}_c$. Two-phase instantaneous voltages e_α, e_β and instantaneous currents i_α, i_β can be obtained by the following transformation.

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = C_{32} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{1}$$

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

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

On the $\alpha - \beta$ plane shown in figure 1, vector $\boldsymbol{e}_\alpha, \boldsymbol{e}_\beta$ and $\boldsymbol{i}_\alpha, \boldsymbol{i}_\beta$ respectively can be synthesized as the voltage vector $\boldsymbol{e}$ and the current vector $\boldsymbol{i}$.

$$\begin{aligned} \boldsymbol{e} &= \boldsymbol{e}_\alpha + \boldsymbol{e}_\beta = e\angle\varphi_e \\ \boldsymbol{i} &= \boldsymbol{i}_\alpha + \boldsymbol{i}_\beta = i\angle\varphi_i \end{aligned} \tag{3}$$

Where e , i is the vector die of vector $\boldsymbol{e}$, $\boldsymbol{i}$ respectively. φ_e, φ_i is the argument of vector $\boldsymbol{e}$, $\boldsymbol{i}$ respectively.

Three-phase circuit instantaneous active current i_p and the instantaneous reactive current i_q respectively are the projection of vector $\boldsymbol{i}$ to vector $\boldsymbol{e}$ and its normal line.

$$i_p = i\cos\varphi \tag{4}$$

$$i_q = i\sin\varphi \tag{5}$$

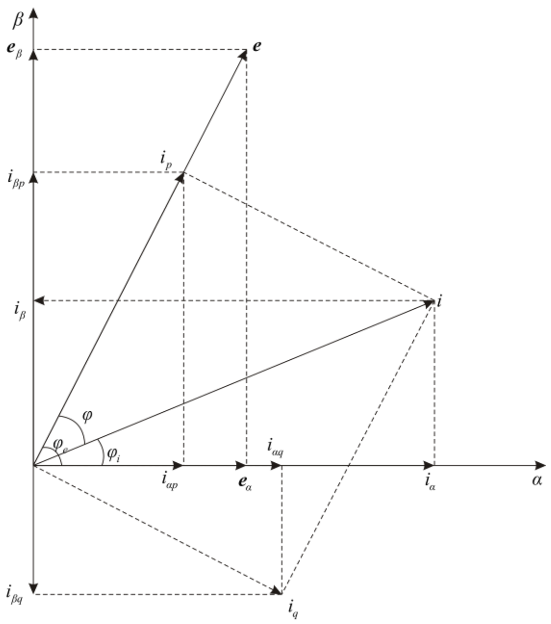


Figure 1. Voltage vector and current vector in $\alpha-\beta$ coordinates

Where $\varphi=\varphi_e-\varphi_i$. i_p and i_q are shown in figure 1.

Three-phase circuit instantaneous active power p (Instantaneous reactive power q) is product of voltage vector die and the three-phase circuit instantaneous active current i_p (instantaneous reactive current i_q).

$$p=ei_p \tag{6}$$

$$q=ei_q \tag{7}$$

Put equations (4), (5) and $\varphi=\varphi_e-\varphi_i$ into (6), (7), it can be rewritten as the following in matrix form.

$$\begin{bmatrix} p \\ q \end{bmatrix}=\begin{bmatrix} e_\alpha & e_\beta \\ e_\beta & -e_\alpha \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}=C_{pq}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{8}$$

Where $C_{pq}=\begin{bmatrix} e_\alpha & e_\beta \\ e_\beta & -e_\alpha \end{bmatrix}$.

Therefore, a method of harmonic and reactive current detection---- i_p , i_q harmonics detecting method based on instantaneous reactive power theory can be carried out by the calculation of i_p , i_q . The detection method of the principle block diagram is shown in figure 2.

C_{23} is the inverse transformation of C_{32} in figure 2. $C=\begin{bmatrix} \sin\omega t & -\cos\omega t \\ -\cos\omega t & -\sin\omega t \end{bmatrix}$. Here need sine signal $\sin\omega t$ and cosine signal $-\cos\omega t$ in phase with a-phase grid voltage which produced by single phase and phase lock loop 1-phase PLL. i_p , i_q are calculated according to the definition of the front. Then let them go through Low-pass filter and get DC component $\bar{i}_p$, $\bar{i}_q$. Here, $\bar{i}_p$, $\bar{i}_q$ are produced by fundamental current i_{af} ,i_{bf} ,i_{cf} . Therefore

$$\begin{bmatrix} i_{af} \\ i_{bf} \\ i_{cf} \end{bmatrix}=C_{23}C\begin{bmatrix} \bar{i}_p \\ \bar{i}_q \end{bmatrix} \tag{9}$$

If respectively subtract i_{af} ,i_{bf} ,i_{cf} from i_a ,i_b ,i_c , we get corresponding harmonic components i_{ah} ,i_{bh} ,i_{ch} .

If cut off the access of i_q calculation in figure 2, we can detect the harmonic and reactive current of compensation object at the same time. Fundamental active components

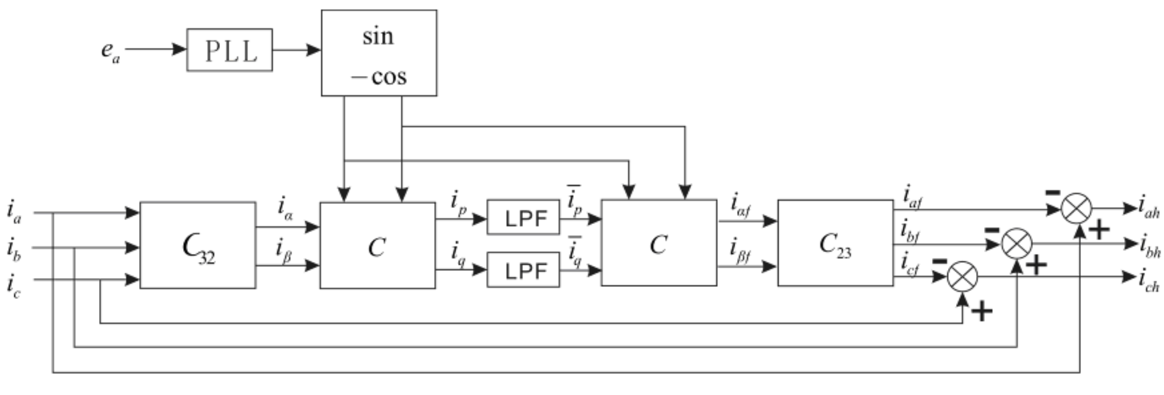


Figure 2. i_p , i_q harmonics detecting method principle diagram

$i_{apf}, i_{bpf}, i_{cpf}$ of current to be detected i_a, i_b, i_c can be calculated by $\overline{i_p}$.

$$\begin{bmatrix} i_{apf} \\ i_{bpf} \\ i_{cpf} \end{bmatrix} = C_{23} C \begin{bmatrix} \overline{i_p} \\ 0 \end{bmatrix} \tag{10}$$

If respectively subtract $i_{apf}, i_{bpf}, i_{cpf}$ from i_a, i_b, i_c, we get the sum of harmonic components and fundamental reactive components.

Because using a low-pass filter to calculate $\overline{i_p}, \overline{i_q}$, so there is some delay in the detection result[9] [10]. But no more than a power cycle.

III. MODELING AND SIMULATION

A. The construction of Matlab simulation model

According to i_p, i_q harmonics detecting method, use Matlab Simulink toolbox to design simulation model. Assume the object to be detected is the current of AC side of three-phase full-controlled bridge rectifier circuit. Its DC side is load of resistance and inductance. Here $R = 50\Omega$, $L = 10$ mH. The power phase voltage is 220V, the frequency is 50HZ. The output voltage of the rectifier is 100V (Phase voltage) and the trigger delay angle is 30°. This kind of model can absorb grid fundamental current so as to produce large amounts of 5th, 7th, 11th, 13th harmonic currents to contaminate grid. The harmonic source simulation model is shown in figure 3.

The simulation model of harmonics detection according to i_p, i_q harmonics detecting method is shown in figure 4. Here, transformation matrix C_{32}, C_{23} and C are respectively made into module packages. The low-pass filter is second-order Butterworth analog low-pass filter. In view of the contradiction between detection accuracy and response time, the cut-off frequency is set to 20HZ.

B. Simulation results and analysis

Launch Matlab/Simulink, start simulation of the model built in the above. The detection object is a-phase current of

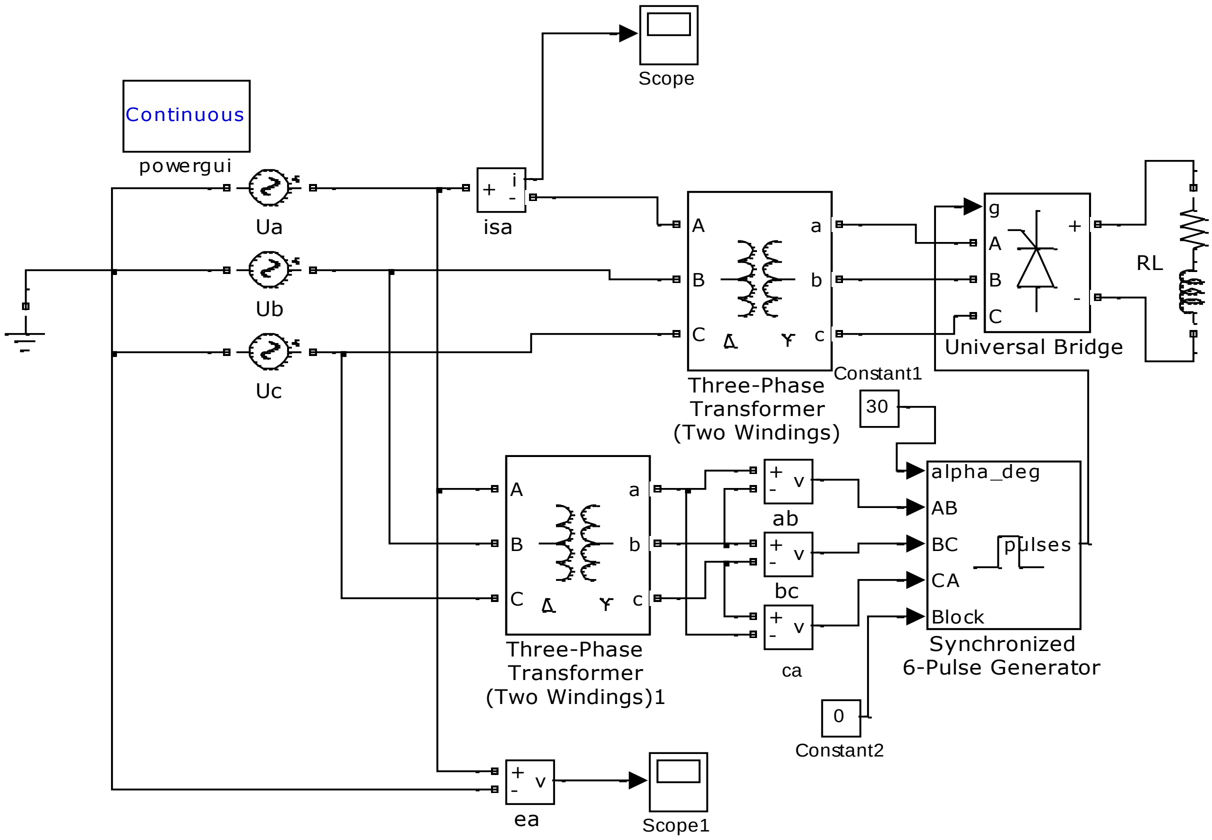


Figure 3. Harmonic source simulation model

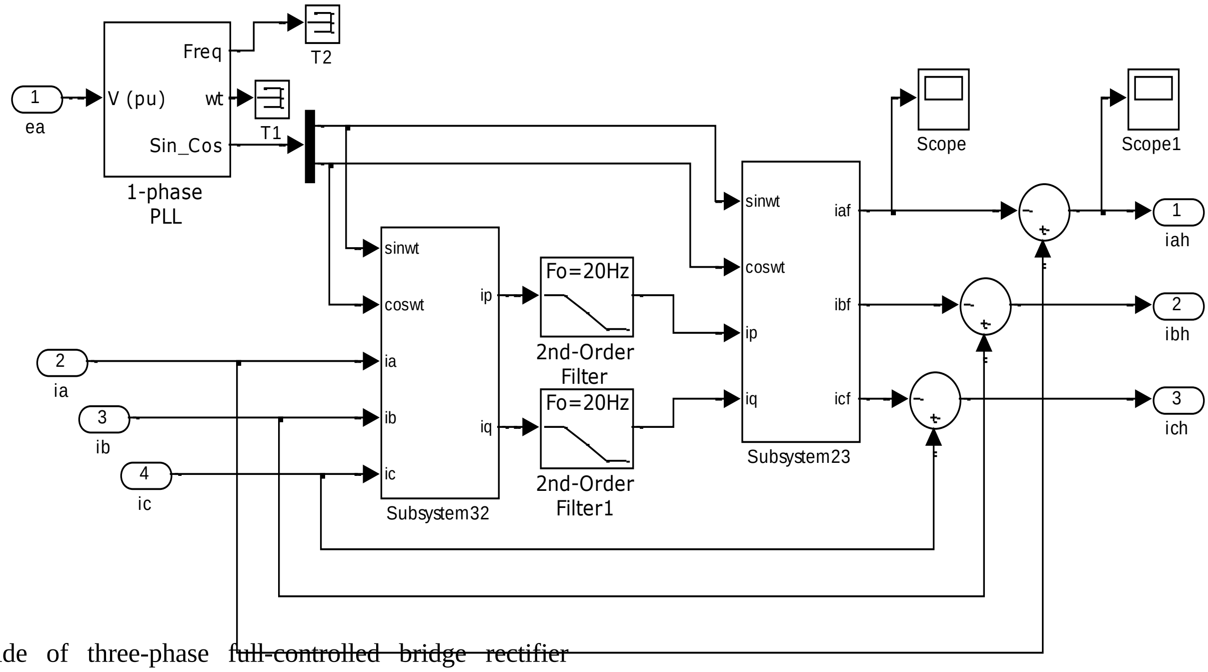


Figure 4. Simulation model of harmonics detection.

AC side of three-phase full-controlled bridge rectifier circuit. Its waveform is shown in Figure 5. The current waveform of the other two phases is same as a-phase but phase respectively lag 120° and 240° .The waveform of fundamental component i_{af} and harmonic component i_{ah} are respectively shown in figure 6 and figure 7.Then disconnect the access of i_q calculation in figure 2,it can get the waveform of fundamental active component i_{apf} and the waveform of the sum of harmonic component and the fundamental reactive component i_{ad} ,which shown in figure 8 and figure 9.

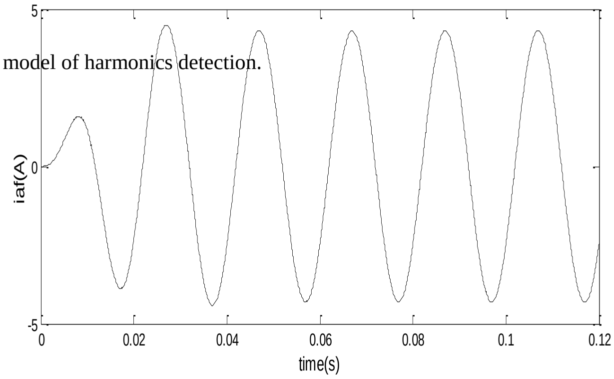


Figure 6. Waveform of fundamental component i_{af}

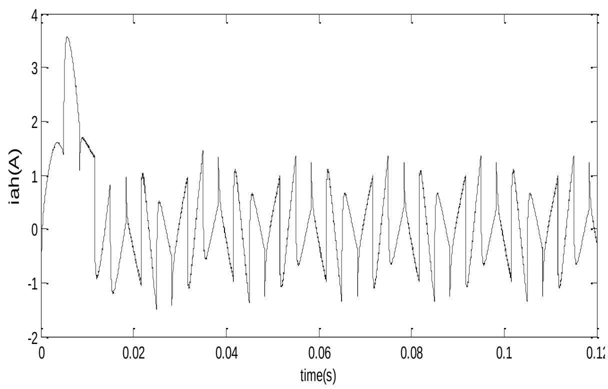


Figure 5. Waveform of harmonic component i_{ah}

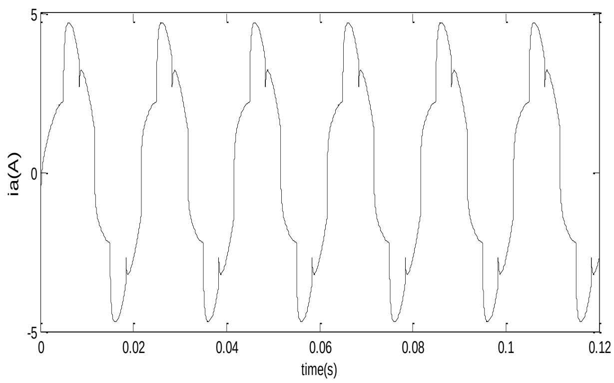


Figure 7. Waveform of a-phase grid current

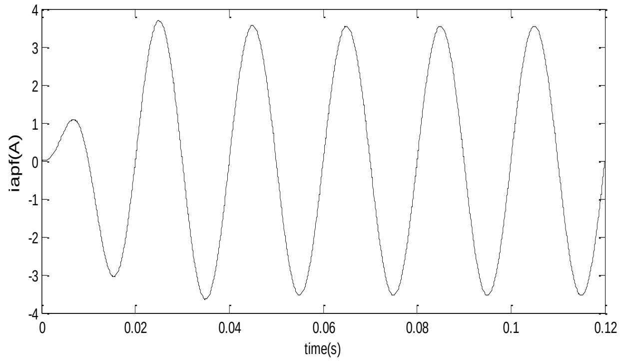
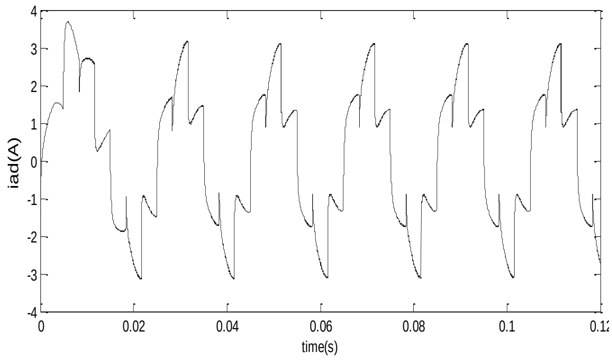


Figure 8. Waveform of fundamental active component i_{apf}



Figuer9. Waveform of the sum of harmonic component and the fundamental reactive component i_{ad}

The analyse of frequency & spectrum of Waveforms in figure 5, figure 6 and figure 7 is shown in table 1.

TABLE I. FREQUENCY & SPECTRUM OF SIMULATION RESULT OF HARMONIC DETECTION TO A-PHASE GRID CURRENT

Harmonic frequency	1	5	7	11	13	17	19
i_a	4.32	0.68	0.26	0.27	0.12	0.16	0.08
i_{af}	4.31	0.00	0.00	0.00	0.00	0.00	0.00
i_{ah}	0.01	0.68	0.26	0.27	0.12	0.16	0.08

According to simulation result and analysis of frequency & spectrum of waveform, it can draw the conclusion that i_p , i_q harmonics detecting method could detect harmonic and reactive current in the grid accurately. It can also accurately isolate the active component and reactive component in the fundamental wave by disconnecting the access of i_q calculation in figure 2.Becaus of the calculation only include $\sin \omega t$ and $\cos \omega t$ of which the phase is the same as the positive sequence voltage of a-phase fundamental wave, the result of fundamental current detection is accurate although power grid voltage is distorted or imbalanced. This can be proved by the figure 6 and figure 8. The detection delay is about 1/3 cycle and the result is accurate when the cut-off frequency of low-pass filter is set to 20HZ. The detection of real-time and accuracy is satisfactory.

IV. SUMMARY

In this paper, a simulation model of harmonic detection based on instantaneous reactive power theory is established by the Matlab/Simulink software. The simulation result proves the validity of the method. The harmonic detection means based on instantaneous reactive power theory can detect harmonic and reactive component in three-phase current precisely and real-time. It can supply reliable harmonic and reactive current for harmonic restraint and reactive power compensation, which is beneficial to solve power quality problems.

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