An New Method for Detecting Harmonic Currents

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Abstract. The widespread use of power electronics has led to increasing problems with harmonics in power systems. The \(i_p-i_q\) detection method is a common method to detect harmonics. If there is a symmetry of the three phases of the power system, the \(i_p-i_q\) detection method can have very large errors in detecting the harmonic current. To solve this problem, an new method for detecting harmonic currents is proposed in this paper. The method solves the phase between the positive sequence voltage of each phase and the actual voltage by using the delay method to obtain the positive sequence fundamental signal of the fundamental current error problem. The simulation was then carried out using MATLAB/SIMULINK, and the simulation results confirmed the method still accurately detects harmonic currents in all cases. Therefore, this method is of great research importance for the elimination of harmonics.

1. Introduction

There has been a great development in science and technology, so that the level of industrial production has been rapidly improved[1]. The non-linear power consumption devices has led to the emergence of harmonic problems, it not only affects the power quality, but also has an impact on the misoperation of the relay protection device in the power system. At present, the elimination of harmonics in the power system is mainly through the filtering process, filtering methods are mainly passive filtering technology and active filtering technology, including the detection of harmonics are mainly instantaneous reactive power detection methods, Fourier analysis detection methods. In actual use \(i_p-i_q\) detection method is more commonly used for instantaneous reactive power, but when there is asymmetry or distortion in the power system, it is used to detect the instantaneous reactive power[2].

When the three-phase voltage is asymmetrical, there is a large error between the harmonics detected by the \(i_p-i_q\) detection method and the actual harmonics, and the real-time detection effect is poor. Therefore, in order to solve the problem that the \(i_p-i_q\) detection method cannot accurately detect harmonics and reactive currents, this article proposes an new method of harmonic current detection, which uses a time delay method to obtain the positive-sequence fundamental signal of the fundamental current. It not only eliminates the need for a low-pass filter, but also provides active and reactive current signals through a simple coordinate transformation. The filtering of waveforms is of great importance.
2. Principle of positive sequence fundamental wave extractor

By using a phase-locked loop (PLL), we obtain a sine signal that is in phase and frequency with the grid voltage[3]. The cosine signal which gives the transformation matrix C, is multiplied by the transformation matrix C. After LPF filtering, the DC component is obtained, and then the respective inverse conversion can be obtained for the fundamental wave active and fundamental wave Reactive Current. A schematic diagram of the conventional-detection algorithm is shown in Figure 1 below.

\[
\begin{align*}
    u_a^+ & = \frac{1}{3}[u_a(t) - u_a(t - T/6) + u_a(t - T/3)] \\
    u_a^- & = u_a(t - T/3)
\end{align*}
\]

The Laplace transformation yields the following results:

\[
\begin{align*}
    u_a(t + T/3) & = \sqrt{2}u_a \sin(\omega t + \theta_a^+) + \sqrt{2}u_a \sin(\omega t + \theta_a^-) \\
    u_a(t - T/3) & = \sqrt{2}u_a \sin(\omega t + \theta_a^-) + \sqrt{2}u_a \sin(\omega t + \theta_a^+) + 2\pi/3
\end{align*}
\]

Because the phase-locked loop extracts the initial phase of the voltage, rather than the initial phase of its positive sequence voltage, it is no longer in the same phase. There is a phase difference between the reactive current detected by the i_p-i_q reactive current detection algorithm and the actual value, and there is a delay of 1-2 cycles, which seriously affects the accuracy and speed of detection.

In order to solve the problem that the harmonic detected by i_p-i_q method has a large error with the actual harmonic in the case of asymmetry or distortion in the power system, and the real-time effect of detection is relatively poor, this paper proposes a new method. The principle is described as follows.

2.1 positive sequence voltage component extraction

When there is asymmetry or distortion in the power system, because of the negative sequence component, the phase difference between the positive sequence component obtained by the PLL and the actual positive sequence voltage phase exists, it affects the test results. When the three-phase voltage in the power system is asymmetric, the T/3 delay method can delay the power grid voltage by 1/3 power frequency cycle. Through the three-phase symmetry principle, the positive sequence and negative sequence components in the three-phase power grid voltage are separated, and the positive sequence components of the voltage are extracted.

\[
\begin{align*}
    u_a^+ & = u_a \sin(\omega t + \theta_a^+) + u_a \sin(\omega t + \theta_a^-) \\
    u_a^- & = u_a \sin(\omega t + \theta_a^- - 2\pi/3) + u_a \sin(\omega t + \theta_a^+ + 2\pi/3) \\
    u_a & = u_a \sin(\omega t + \theta_a^+ - 2\pi/3) + u_a \sin(\omega t + \theta_a^- - 2\pi/3)
\end{align*}
\]

\[
\begin{align*}
    u_a^+ & = [u_a(t) - u_a(t - T/6) + u_a(t - T/3)]/3 \\
    u_a^- & = u_a(t - T/3)
\end{align*}
\]

\[
\begin{align*}
    u_a^+ & = \frac{1}{3}[u_a(t) - u_a(t - T/6) + u_a(t - T/3)] \\
    u_a^- & = u_a(t - T/3)
\end{align*}
\]
Setting the amplitude integral of the sine signal $e(t) = A\sin(\omega_1 t + \theta)$ and delay the sine signal $e(t)$ by 90° to obtain the auxiliary signal $x(t) = A\cos(\omega_1 t + \theta)$.

$$H(s) = \frac{A_w \cos \theta}{s^2 + \omega_1^2} + \frac{A_s \sin \theta}{s^2 + \omega_2^2}$$

$$X(s) = \frac{A_s \cos \theta}{s^2 + w_1^2} - \frac{A_w \sin \theta}{s^2 + w_2^2}$$

$$Y(s) = \frac{s}{s^2 + \omega_3^2} \left( \frac{A_w \cos \theta}{s^2 + \omega_1^2} + \frac{A_s \sin \theta}{s^2 + \omega_2^2} \right) + \frac{w_i}{s^2 + \omega_i^2} \left( \frac{A_s \cos \theta}{s^2 + \omega_1^2} - \frac{A_w \sin \theta}{s^2 + \omega_2^2} \right)$$

Combined (6)-(7) equation yields

$$Y(s) = \frac{s}{s^2 + w_1^2} E(s) + \frac{w_i}{s^2 + w_i^2} X(s)$$

The transfer function can be obtained as follow:

$$H(s) = \frac{Y(s)}{X(s)} = \frac{s}{s - j\omega}$$

When a certain frequency condition is met, (9) has amplitude-frequency characteristics that produce resonance at the angular frequency. Thus using the amplitude integrator a positive sequence fundamental extractor can be obtained as shown in Figure 2.

**Figure 2.** Sequential base wave extractor

2.2 improved $I_p-I_q$ detection model

The principle of the improved harmonic and reactive current detection is shown in Figure 3.

**Figure 3.** Schematic diagram of improved $i_p-i_q$ detection
Setting the three-phase voltage as \( u_a, u_b, u_c \), and through the T/3 delay method can get the positive-sequence component of the A-phase voltage, at this time there is no need for a phase-locked loop, only a function transformation can be obtained corresponding to the voltage.

\[
f_i = \frac{u_i}{\sqrt{(u_i^a)^2 + (u_i^b)^2}}
\]

\[
f_i = -\frac{u_i}{\sqrt{(u_i^a)^2 + (u_i^b)^2}}
\]

\[
sin(\theta) = \frac{u_i^a}{\sqrt{(u_i^a)^2 + (u_i^b)^2}}
\]

\[
-cos(\theta) = -\frac{u_i^b}{\sqrt{(u_i^a)^2 + (u_i^b)^2}}
\]

These functions form the matrix C and D of the coordinate transformation of the \( i_p-i_q \) detection system by eliminating errors caused by asymmetrical phase differences in voltage.

\[
D = \sqrt{\frac{2}{3}} \begin{bmatrix} sin(\omega t) & -cos(\omega t) \\ -sin(\omega t + \frac{\pi}{3}) & \cos(\omega t + \frac{\pi}{3}) \\ -sin(\omega t - \frac{\pi}{3}) & \cos(\omega t - \frac{\pi}{3}) \end{bmatrix}
\]

After \( \alpha, \beta \) transformations can be obtained:

\[
\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = C_{32} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}
\]

The DC component of the current can be obtained directly from the extractor by the Park transform and positive sequence integration.

\[
\begin{bmatrix} i_q \\ i_p \end{bmatrix} = D \begin{bmatrix} i_q \\ i_p \end{bmatrix} = \sqrt{2} \begin{bmatrix} I_i \sin(\omega t + \theta_1) \\ I_i \sin(\omega t + \theta_1 - \frac{2\pi}{3}) \\ I_i \sin(\omega t + \theta_1 + \frac{2\pi}{3}) \end{bmatrix}
\]

The harmonic component can be obtained by subtracting the fundamental component from the three-phase current \( i_a, i_b, i_c \). The reactive current is obtained by disconnecting the DC active channel and performing a coordinate transformation of the DC reactive power only.

\[
\begin{bmatrix} i_{a_q} \\ i_{b_q} \\ i_{c_q} \end{bmatrix} = D \begin{bmatrix} 0 \\ I_q \\ I_q \end{bmatrix} = \sqrt{2} I_i \begin{bmatrix} \cos(\omega t) \\ \cos(\omega t - \frac{2\pi}{3}) \sin \theta_1 \end{bmatrix}
\]

3. Simulation verification and result analysis
To research the effect of the new \( i_p-i_q \) method, this paper uses Matlab / Simulink simulation software to simulate[5]. Considering the voltage asymmetry and distortion of three-phase power grid, the detected fundamental and harmonic components are compared with the actual fundamental and
harmonic components. In the experiment, the distortion voltage of the three-phase bus is the same as the above-mentioned distortion voltage, which is as follows:

\[
\begin{align*}
    v_a &= 220\sqrt{2}\sin(100\pi t) + 60\sin(200\pi t) + 35\sin(400\pi t) \\
    v_b &= 220\sqrt{2}\sin(100\pi t - 2\pi/3) + 56\sin(200\pi t + 2\pi/3) + 44\sin(300\pi t - 2\pi/3) + 33\sin(400\pi t + 2\pi/3) \\
    v_c &= 220\sqrt{2}\sin(100\pi t + 2\pi/3) + 57\sin(200\pi t + 2\pi/3) + 42\sin(300\pi t - 2\pi/3) + 37\sin(400\pi t - 2\pi/3)
\end{align*}
\]

The load in the experiment is a three-phase rectifier bridge \[6\], where the inductance is 15mH and the resistance is 8 ohms. The voltage source is a symmetrical RMS voltage of 220V, and add a certain amount of negative sequence components to the three-relative voltage.

Figure 4(a). actual harmonic current waveform of A phase

Figure 4(b). Harmonic current detected by phase A

Figure 4(c). Differential current waveform between the harmonic current detected in phase A and the actual harmonic current

A comparison of Figure 4(a) and Figure 4(b) shows that the \(i_r-i_q\) method still detects in the bus when the three-phase voltage is distorted. By observing Figure 4(c), it can be found that the difference between the harmonic current detected by this method and the actual harmonic current before 0.15 seconds has But after 0.15 seconds, the error disappears. The main reason is that the positive sequence component of A-phase voltage can be obtained by \(T/3\) delay method. At this time, the phase angle of the corresponding A-phase voltage can be obtained without phase-locked loop and only a function transformation, and the transformation matrix can be carried out without collecting the instantaneous voltage of each phase of the bus for calculation and transformation, because this distorted bus voltage has no impact on the analysis and calculation of harmonics.

4. Conclusion

In this paper, the non-linear power consumption devices has led to the emergence of harmonic problems, an new method of harmonic detection in power system is proposed by using the T/3 delay method, and MATLAB / Simulink simulation software was used for the theoretical analysis and study. The simulation results validate that the improved method can detect reactive currents quickly and accurately When there are asymmetries in the power system, the method improves detection accuracy, and eliminates the need for a low-pass filter to avoid the time delay problem caused by low-pass
filtering, which improves detection accuracy. It is important for the APF to achieve real-time compensation of harmonics and reactive currents and provide appropriate reference currents.

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