Research on a Fundamental and Harmonic Detection Method Based on D-Q Rotating

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Abstract. The widespread use of power electronics in power systems has led to increasingly serious power quality problems in power systems. Active power filters play an important role in governing the harmonics of power systems. The fast and accurate detection of fundamental and harmonic currents in power systems is one of the key aspects of power filters to manage harmonics. In this paper, a new detection method for the fundamental or the nth harmonic component of the fundamental by presetting the frequency of the d-q conversion matrix is proposed. Analysis of simulation results shows that the detection method is not affected by the voltage distortion or asymmetry of the three-phase circuit, and that the results for fundamental and harmonic detection. The ability to accurately reflect changes in frequency and amplitude excursions.

1. Introduction

When a fault occurs in a power system, the fault signal contains not only the power frequency component, but also the harmonic component and the different frequency components of the acyclic component[1]. Therefore it is very important to distinguish the fundamental from a certain number of double harmonic frequencies from the faulty electrical quantity. Currently the main harmonic extraction methods are FFT and DFT, but both algorithms have time delays and computationally large problems [2], real-time detection based on instantaneous reactive power theory can solve this problem. The method that can make the actual voltage distortion of the power grid does not affect the detection accuracy and has fast dynamic response speed. In this paper, a new d-q coordinate transformation detection method is proposed, which mainly uses a circuit without phase-locked loop to set d-q in advance. The matrix frequency is transformed to accurately detect the various fundamental frequency components of the load current. The method is independent of voltage distortion and can also be applied in the case of asymmetric loads. Finally, a simulation analysis of the improved d-q detection method is studied using MATLAB/Simulink. The results show that the method is able to detect fundamental and harmonics in power systems well.

2. The principle of harmonic detection

The d-q coordinate transformation detection method is based on the principle of using the park transform to convert the three-phase voltage in the ABC coordinate system to d-q-0[3]. The coordinate system, which is mainly obtained by simplifying the theory of d-q-0 coordinate transformation. There are positive, negative and zero-order harmonic components in the power system, and the value of the
zero-order component will become zero when we perform the coordinate transformation. The expressions of harmonic component of load voltage in the power system are as follows:

\[
U_a = U_{1n} \sin(n wt + \phi_{1n}) + U_{2n} \sin(n wt + \phi_{2n})
\]

\[
U_b = U_{1n} \sin(n wt + \phi_{1n} - \frac{2\pi}{3}) + U_{2n} \sin(n wt + \phi_{2n} - \frac{2\pi}{3})
\]

\[
U_c = U_{1n} \sin(n wt + \phi_{1n} + \frac{2\pi}{3}) + U_{2n} \sin(n wt + \phi_{2n} + \frac{2\pi}{3})
\]

\[\text{(1)}\]

\(U_{1n}, \quad \phi_{1n}\) are the effective value and initial phase angle of each positive sequence current respectively, and \(U_{2n}, \quad \phi_{2n}\) are the effective value and initial phase angle of each negative sequence current respectively, subscript "1" means positive order, subscript "2" means negative order, subscript "n" means the nth harmonic of the fundamental. The d-q-0 transformation of equation (1) yields:

\[
\begin{bmatrix}
\frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\
\cos m wt & \cos (m wt - \frac{2\pi}{3}) & \cos (m wt + \frac{2\pi}{3}) \\
\sin m wt & \sin (m wt - \frac{2\pi}{3}) & \sin (m wt + \frac{2\pi}{3})
\end{bmatrix}
\begin{bmatrix}
U_a \\
U_b \\
U_c
\end{bmatrix}
= Q
\begin{bmatrix}
U_a \\
U_b \\
U_c
\end{bmatrix}
\]

\[\text{(2)}\]

From equation (2) it is found that the nth positive-sequence component can be transformed into the n±mth component in 0-d-q coordinates by a 0-d-q transformation. The zero sequence component is always zero. so the transformation matrix Q can be written as:

\[
Q = \frac{2}{3}
\begin{bmatrix}
\cos m wt & \cos (m wt - \frac{2\pi}{3}) & \cos (m wt + \frac{2\pi}{3}) \\
-\sin m wt & -\sin (m wt - \frac{2\pi}{3}) & -\sin (m wt + \frac{2\pi}{3})
\end{bmatrix}
\]

\[\text{(3)}\]

\[
Q^{-1} = \begin{bmatrix}
\cos m wt & -\sin m wt \\
\cos (m wt - \frac{2\pi}{3}) & -\sin (m wt - \frac{2\pi}{3}) \\
\cos (m wt + \frac{2\pi}{3}) & -\sin (m wt + \frac{2\pi}{3})
\end{bmatrix}
\]

\[\text{(4)}\]

Using the low-pass filter to eliminate the AC components of the D and q axis components of the Q matrix after the d-q coordinate transformation (as shown in Figure 1), then d-q inverse transformation of the resulting n-positive-sequence components converted to the d and q axes to obtain the n-positive-sequence components of the abc three-phase(Q-1 as shown in (4) above).

\[
U_{abc} = Q^{-1} \tilde{U}_{dq}
\]

\[\text{(5)}\]
The first subscript "1" of $U_{1n}$ in the formula represents the positive sequence, and the second subscript "n" represents the nth harmonic of the fundamental.

### 3. Preset d-q transformation matrix frequency to realize harmonic current detection

The above principle reveals that in order to detect the fundamental or harmonic component, the elements in the d-q transformation matrices $Q$ and $Q^{-1}$ must be determined in advance, and also due to the use of PLL (phase-locked loop) circuits to generate synchronized sine and cosine signals, which will result in a three-phase current. The accuracy of the fundamental frequency and the initial phase angle is affected. Therefore, by presetting the fundamental and harmonic frequencies in the power system, the fundamental frequency 50 Hz. The fundamental and harmonic frequencies of 50nHZ are set according to the actual power system, so that the detected fundamental and harmonic frequencies and the actual power system are the same. The power system is consistent. Thus the matrix $Q$ and the matrix of $w=314$ are determined, while the detection of the fundamental voltage and current or the nth harmonic component is not affected by the the effect of a change in the initial phase angle of the harmonic current.

Because the frequency of the power grid is affected by various factors in the actual power system, the frequency can not be kept at 50Hz all the time. If the frequency of the power grid voltage in some period of time reaching 49.4Hz, the theoretical analysis of harmonic current detection is realized by presetting the frequency of d-q transformation matrix in advance. Then, the DC component obtained by formula (8) is actually a fluctuating AC component with the frequency of 0.6Hz. Since the filtering range of low-pass filter is generally 5 ~ 30Hz, it can be found that the AC component will not be removed. Through the inverse transformation of formula (6), the AC component can still be transformed into the fundamental wave of the power grid with the frequency of 49.6Hz. Therefore, the results of detecting fundamental and nth harmonic components by this method in power system will not be affected.

$$\begin{bmatrix} U_d \\ U_q \end{bmatrix} = \begin{bmatrix} U_{1n} \sin \phi_{1n} \\ -U_{1n} \cos \phi_{1n} \end{bmatrix}$$

$$\begin{bmatrix} U_{an} \\ U_{bn} \\ U_{cn} \end{bmatrix} = Q^{-1} \begin{bmatrix} U_d \\ U_q \end{bmatrix} = U_{1n} \begin{bmatrix} \sin(nwt + \phi) \\ \sin(nwt + \phi - \frac{2\pi}{3}) \\ \sin(nwt + \phi + \frac{2\pi}{3}) \end{bmatrix}$$ (7)
4. Design of low pass filter

Butterworth, one of the common low-pass filters, is mainly used in this paper for its amplitude frequency characteristics of no attenuation and monotonous reduction for DC components. Four kinds of LPF are simulated and analyzed by MATLAB simulation software. The Bode diagram of four kinds of low-pass filters in which the sampling frequency is set to 500Hz, the order is set to 2, and the cut-off frequency is set to 20Hz.

Figure 2 shows the Butterworth bode chart when the cut-off frequency is 5Hz, 10Hz, 20Hz and 30Hz respectively. Setting the cut-off frequency of the low-pass filter to less than 50Hz. By analyzing Figure 2, it can be found that when the cut-off frequency is greater than 10Hz, the amplitude is not zero at 50Hz, and when the cut-off frequency is greater than or equal to 30Hz, the amplitude is not zero at 100Hz. Therefore, the cut-off frequency can be set to 20Hz when detecting the fundamental wave of electrical quantity and 10Hz when detecting the nth harmonic component[5].

![Figure 2. Butterworth bode chart with cut-off frequency of 5Hz, 10Hz, 20Hz and 30Hz respectively](image)

5. Simulation verification and result analysis

Using MATLAB for modeling and simulation analysis, the three-phase voltage fundamental frequency is set to 50 Hz in the power system simulation setup. The impedance coefficient of the three lines is set from 0.01343 to 0.3574ohms/km, and the inductance coefficient is 0.83233e-3~4.3576e-3H/km, the tolerance factor is 11.63e-9~82.573e-9F/km with 450 km of transmission line and 180 watts of useful power at the end of the transmission line. The large gap between the fundamental signal and the actual fundamental signal prior to 0.02s. After 0.02s, the fundamental signal starts to track the actual fundamental signal and remains stable. Figure 3 shows the three-phase voltage of power system, and Figure 4 shows the simulation results of detecting three-phase voltage fundamental wave by d-q transformation. From Figure 5, we can see more clearly that before 0.02s, the difference between the detection signal and the actual basic signal is slow. The difference from 0.04s to 0.08s is reduced, and the oscillation will slowly decrease from a larger difference of 1, and the difference will remain at 0 after 0.02s. From Figure 6, we can also determine that the difference between the two is zero after one cycle, and Figure 7 shows that 5HZ and 10HZ low-pass filter simulated waveforms with a cutoff frequency of 5HZ over three cycles. The low-pass filter with a cut-off frequency of 10Hz is fast and accurate in one cycle. The trace on the third harmonic signal is to be measured, basically no distortion. By comparison, it can be found that the cut-off frequency of the low-pass filter with a cut-off frequency of 5 HZ is set too small. In Figure 8, it can be found that the cut-off frequency of 20 Hz low-pass filter affects the detection speed more than that of 10 Hz low-pass filter. The low-pass filter is fast, but the distortion is more remarkable, which affects the accuracy of measurement and indirectly indicates that the cut-off frequency of 20 Hz Has a strikingly negative influence. Therefore, the cut-off
frequency between 5-20Hz is more appropriate.

Figure 3. Three phase voltage to be measured

Figure 4. Simulation results of three-phase voltage fundamental wave detected by d-q transformation

Figure 5. error analysis

Figure 6. tracking error analysis of fundamental mutation Signal wave

Figure 7. FC is the third harmonic detection of 10Hz and 5Hz

Figure 8. FC is the third harmonic detection of 10Hz and 20Hz

6. Conclusion
The d-q-transformed fundamental and harmonic detection method can lead to large errors in detection results when asymmetries are present in the power system. So by transforming the fundamental or n±mth harmonic into a d-q coordinate system, the DC component is obtained using a low-pass filter.
The detection method of the positive sequence component of the fundamental or nth harmonic of the signal under test by inverse transformation, and MATLAB simulation software. The presented analysis reveals that it can accurately detect the fundamental or nth harmonic network. At the same time, the accuracy of the voltage detection does not affect the distortion of the actual three-phase circuit, and the detection results reflect the changes in frequency and amplitude over time.

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