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Study on Harmonic Detection and Suppression Methods of EAF

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Abstract

This paper presents an improved i_p - i_q detection method for three-phase four-wire electric arc furnace (EAF) systems based on the instantaneous reactive power theory, which can be applied not only to stationary load, but also to non-stationary load with large fluctuations in electrical parameters. Simulation experiments show that this detection method is indeed capable of fundamental and harmonic separation to achieve the purpose of harmonic detection.

Keywords: power quality; reactive power compensation; harmonic detection; harmonic suppression

1. Introduction

In recent years, along with the economic development, China pays more and more attention to the steelmaking industry and smelting technology, and a large number of EAF equipments are put into production and their capacity is also increasing. The working characteristics of EAF equipments decide that EAF will result in serious harmonic pollution during smelting including voltage flicker, load imbalance and low power factor, etc. The impact of harmonic pollution is very wide. According to the characteristics of EAF, this paper presents a harmonic detection method for three-phase four-wire EAF based on the instantaneous reactive power theory, which can accurately detect harmonic current and has very good filtering effect for STATCOM devices of high-order harmonic application.

2. Harmonic Current Detection Methods

Because both compensation device and filtering device take reactive current and distorted current as the control target, the instantaneous change in the system current must be first detected to achieve the desired compensation and filtering effect. The accuracy of detection has a direct impact on the accuracy of devices. To select an appropriate detection method is of great significance to compensation devices. At present, the harmonic detection methods generally selected are instantaneous reactive power theory, filtering technology, detection method based on the definition of *Fryze* power and wavelet transform, *etc*.

In recent years, people began to pay attention to the harmonic detection method based on the instantaneous reactive power theory. This method is simple and effective and is successfully applied to engineering. For this reason, this chapter will give a further introduction to the theory.

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2.1. Instantaneous Reactive Power Theory

The instantaneous reactive power theory was first developed by a Japanese scholar for three-phase three-wire system. However, the current situation is that most projects, especially EAF systems, generally use three-phase four-wire system, so after years of continuous research and improvement of scholars from various countries, the instantaneous reactive power theory based on the α, β and 0 coordinate system is established. That is what this paper introduces. As shown in Figure 1, it is assumed that the angle difference between the three-phase stator windings of a synchronous motor in the space is 120°. When the angle difference between the three-phase sinusoidal AC passing through the windings in the time is 120°, the three-phase AC can form a magnetic field with an angular velocity of ω . If it is defined that there are α, β and 0 three-phase windings in a space and they are perpendicular to each other, when the angle difference between the three-phase AC passing through the windings in the time is 90°, a rotating magnetic field can also be formed in the space, which is equivalent to the three-phase windings.

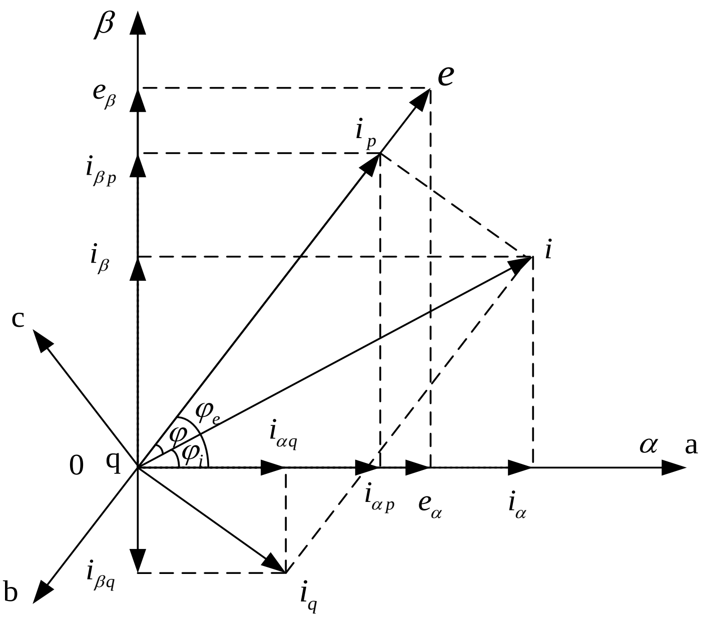

Figure 1. Vector Correlations of α, β and 0 Coordinates

Referring to the current vector decomposition method in the abc three-phase coordinate system, the space current vector $i_{\alpha\beta 0}$ can be decomposed into the sum of two vectors. These two vectors are orthogonal to each other, one of which is $i_{p\alpha\beta 0}$ that is the projection of $i_{\alpha\beta 0}$ on $e_{\alpha\beta 0}$ and the other is $i_{q\alpha\beta 0}$ that is orthogonal to the space voltage vector $e_{\alpha\beta 0}$. It is assumed that $i_{p\alpha\beta 0} = \begin{bmatrix} i_{\alpha p} & i_{\beta p} & i_{0p} \end{bmatrix}^T$, $i_{q\alpha\beta 0} = \begin{bmatrix} i_{\alpha q} & i_{\beta q} & i_{0q} \end{bmatrix}^T$.

In α, β and 0 coordinate system, active power and reactive power can be expressed as:

$$p = e_{abc} \cdot i_{abc} = C^T_{3/2} e_{\alpha\beta 0} \cdot C^T_{3/2} i_{\alpha\beta 0} = e_{\alpha\beta 0} \cdot i_{p\alpha\beta 0} \tag{1}$$

$$q = e \times i = C^T_{3/2} e_{\alpha\beta 0} \times C^T_{3/2} i_{\alpha\beta 0} = e_{\alpha\beta 0} \times i_{q\alpha\beta 0} \tag{2}$$

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2.2. i_p - i_q Algorithm

The i_p - i_q algorithm is based on the instantaneous power theory. Assuming that three-phase voltage waveforms are symmetrical and distortion-free, the instantaneous value of three-phase voltage and current is e_a , e_b , e_c , i_a , i_b and i_c respectively. Assuming that three-phase grid voltage waveforms are symmetrical and distortion-free, the i_p - i_q algorithm is derived based on the instantaneous reactive power theory. However, in fact, system voltage waveforms are always asymmetric or distorted. In this case, you may use the i_p - i_q algorithm to monitor the desired current components. See Figure.2 for the specific implementation process of the i_p - i_q algorithm.

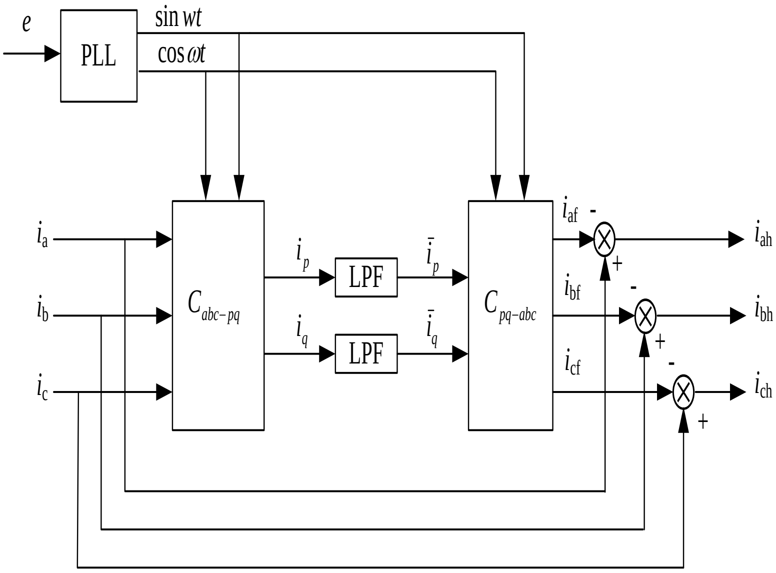

Figure 2. Implementation Process of i_p-i_q Algorithm

2.3. Improved i_p - i_q Algorithm

In actual engineering projects, the i_p - i_q algorithm is usually used for harmonic detection, but as far as the current situation is concerned, the i_p - i_q algorithm is not applicable any more. Especially for EAF systems, it needs to be modified and improved. The voltage of general EAF systems has been tuned into sine wave of known amplitude and phase, so there is no need for coordinate transformation and the process for solving active power p and reactive power q in between may be omitted. This omits a large number of calculations.

First, phase voltage e and phase current i are assumed as:

$$e = \cos \omega_0 t \tag{3}$$

$$i = \sum_{k=1}^{\infty} \sqrt{2} I_k \cos(k\omega_0 t + \ _k) \tag{4}$$

Then, active current $i_p^{'}$ and reactive current $i_q^{'}$ in the abc coordinate system are solved as follows:

$$i_p^{'} = i\cos\omega_0 t = \sum_{k=1}^{\infty}\frac{\sqrt{2}I_k}{2}\{\cos[(k-1)\omega_0 t + \varphi_k] + \cos[(k+1)\omega_0 t + \varphi_k]\} \quad (5)$$

$$i_q^{'} = i\sin\omega_0 t = \sum_{k=1}^{\infty}\frac{\sqrt{2}I_k}{2}\{\sin[(k+1)\omega_0 t + \varphi_k] - \sin[(k-1)\omega_0 t + \varphi_k]\} \quad (6)$$

Eq.(6) can be written as $\begin{bmatrix} i_p^{'} \\ i_q^{'} \end{bmatrix} = C_1 i$ (7)

After $i_p^{'}$ and $i_q^{'}$ passing LPF filtering, their DC components $\bar{i}_p^{'}$ and $\bar{i}_q^{'}$ are obtained:

$$\bar{i}_p^{'} = \frac{\sqrt{2}}{2}I_1\cos\varphi_1 \quad (8)$$

$$\bar{i}_q^{'} = \frac{\sqrt{2}}{2}I_1\sin\varphi_1 \quad (9)$$

From the above equations, we know that the DC component $\bar{i}_p^{'}$ is proportional to the fundamental active power, so $\bar{i}_p^{'}$ can control the active power; the DC component $\bar{i}_q^{'}$ is inversely proportional to the fundamental reactive power, so $\bar{i}_p^{'}$ can control the reactive power.

The instantaneous value of fundamental current can be speculated from Eq.(4) as:

$$i_1 = \sqrt{2}I_1\cos(\omega_0 t + \varphi_1) = 2[\bar{i}_p^{'}\cos\omega_0 t + \bar{i}_q^{'}\sin\omega_0 t] \quad (10)$$

We make that

$$C_2 = [2\cos\omega_0 t \; 2\sin\omega_0 t] \quad (11)$$

Harmonic current can be obtained by deducting i_1 from the instantaneous value of current. See Figure.3 for the implementation process of the improved $i_p - i_q$ algorithm.

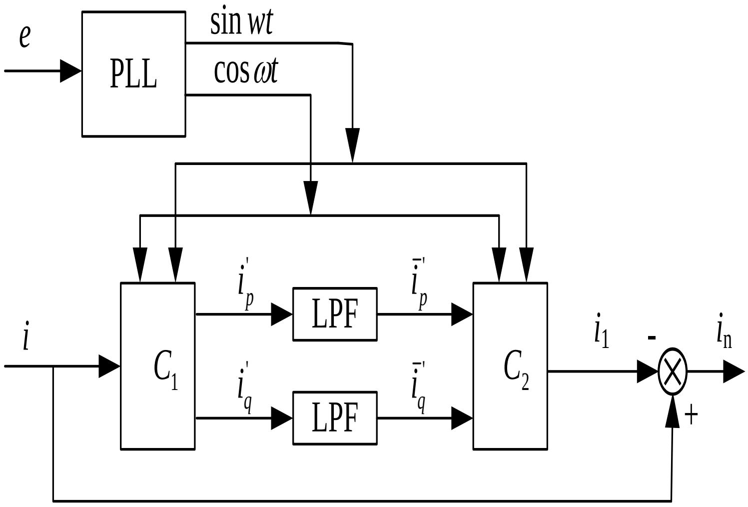

Figure 3. Implementation Process of Improved $i_p - i_q$ Algorithm

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Below is a detailed description on the improved i_p - i_q algorithm. If we want to detect the current of the nth harmonic.

At this time, Eq.(5) and (6) change to:

$$i_p^{'} = i\cos n\omega_0 t = \sum_{k=1}^{\infty}\frac{\sqrt{2}I_k}{2}[\cos(k\omega_0 t + n\omega_0 t + \varphi_k) + \cos(k\omega_0 t - n\omega_0 t + \varphi_k)] \tag{12}$$

$$i_q^{'} = i\sin n\omega_0 t = \sum_{k=1}^{\infty}\frac{\sqrt{2}I_k}{2}[\sin(k\omega_0 t + n\omega_0 t + \varphi_k) - \sin(k\omega_0 t - n\omega_0 t + \varphi_k)] \tag{13}$$

After $i_p^{'}$ and $i_q^{'}$ passing LPF filtering, their corresponding DC components $\bar{i}_p^{'}$ and $\bar{i}_q^{'}$ are obtained:

$$\bar{i}_p^{'} = \frac{\sqrt{2}}{2}I_n\cos\varphi_n \tag{14}$$

$$\bar{i}_q^{'} = -\frac{\sqrt{2}}{2}I_n\sin\varphi_n \tag{15}$$

3. System Modeling and Waveform Analysis

3.1. System Modeling

The simulation model of EAF mainly includes a signal generation module, a three-phase PLL and a harmonic detection module, in which harmonic detection module is the most important and mainly consists of such several parts as $abc/dq0$, PI loop and PLL (see Figure 4). Harmonic detection module uses the improved i_p - i_q harmonic current detection method to transform the three-phase current outputted from the low-voltage side of EAF transformers from abc system to $dq0$ system and then extracts harmonics to obtain the following parameters after phase reversal: baseband signals and all harmonics extracted.

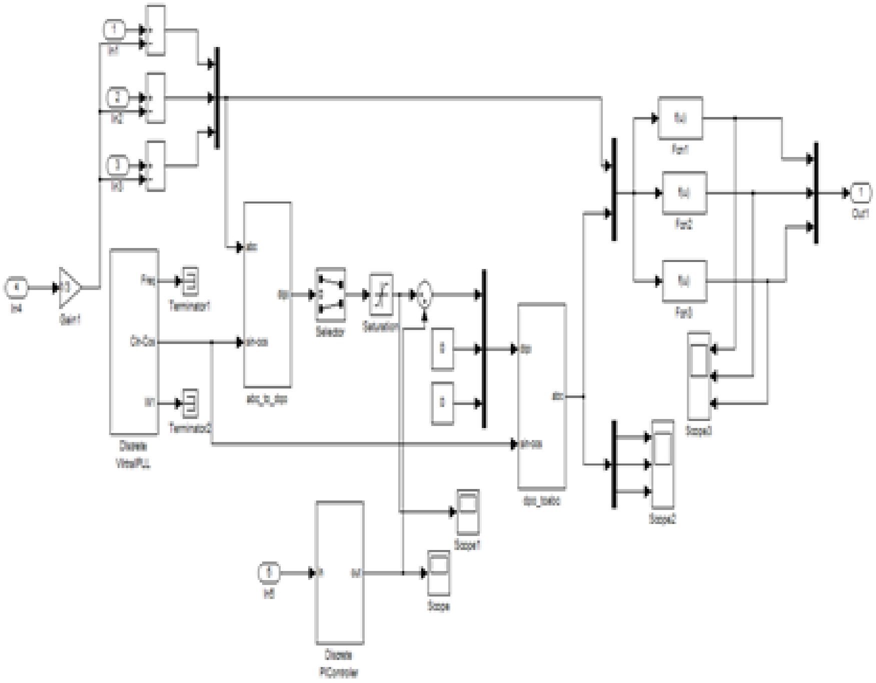

Figure 4. Harmonic Detection Module

3.2. Simulation Waveform Analysis

Taking A-phase current for example, Figure 5 shows the output waveform of an EAF transformer, from which we can see that the current waveform is seriously distorted and asymmetric, indicating that the signal contains a large amount of harmonics.

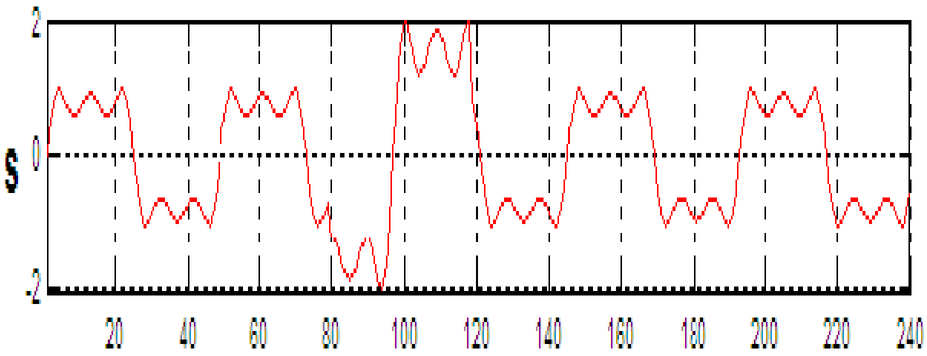

Figure 5. A-phase Current at Output Terminal of EAF Transformer

The A-phase current signal should be detected with the improved $i_p - i_q$ method to obtain fundamental current and harmonic current (see Figure 6). In the figure, a_4 contains only fundamental frequency and is fundamental current, and d_1, d_2, d_3 and d_4 correspond to the first, third, fifth and seventh harmonic respectively. It indicates that the improved $i_p - i_q$ method can completely separate the fundamental and harmonic signals in current signals, accurately detect harmonic components and has good effect.

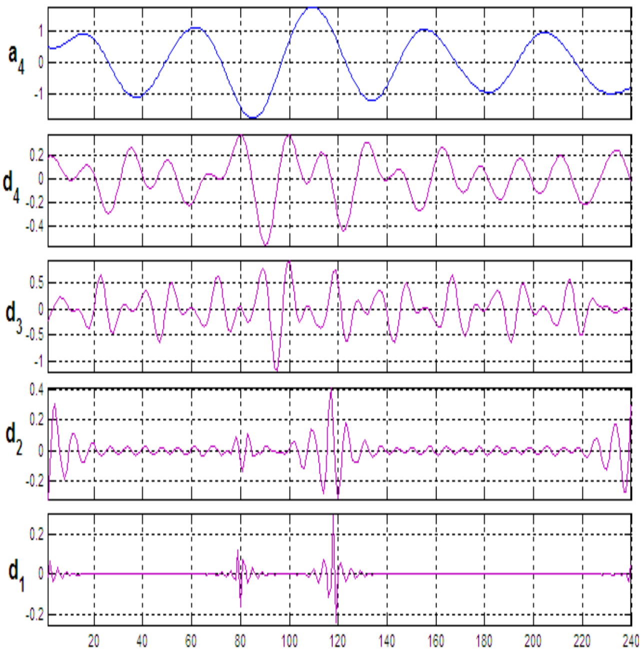

Figure 6. Current Waveforms Detected

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4. Conclusions

In view of the increasingly serious harmonic pollution problem of EAF systems, this paper presents an improved i_p - i_q detection method of harmonic current. The method is developed based on the instantaneous reactive power theory and is mainly used to detect the harmonic current of EAF systems and build EAF simulation models. The simulation graphics show that the i_p - i_q method can accurately detect the harmonic current of three-phase four-wire EAF systems, completely separate it from the fundamental signals in current signals and has high accuracy and good effect.

References

[1] S. Varadan, "A New Time Domain Voltage Source Model for an Arc Furnace Using EMPT", IEEE Trans on Power Delivery, **(2012)**.
[2] S. Bhacharya, D. Div and B. Banerjee, "Synchronous Reference Frame Based Harmonic Isolator Using Series Active Filter", Proc. EPE, Italy, **(2010)**.
[3] H. Cheng, P. Lioa and Z. Chen, "Optimal Selection of Parameters in Electric Power Filter", Power System Technology, **(2013)**.
[4] Erinmez.IAed. Static Var Compensators Working Group Task Force on SVC. CIGRE, **(2011)**.
[5] E. H. Chen, "Using a Static Var Compensator to balance a distribution system", IEEE Transactions on Industry Application, **(2010)**.
[6] R. Teodorescu and F. Blaabjerg, "Flexible control of small wind turbines with grid failure detection operating in stand-alone and gridconnected model", IEEE Transactions On Power Electronics, vol. 19, no. 5, **(2010)**, pp.1323-1332.
[7] Y. Yaomin and F. Yu, "Self-optimizing control of permanent magnet synchronous generator wind power generation system", Transactions of China Electrotechnical Society, vol. 17, no. 6, **(2012)**, pp. 82-86.
[8] F. S. Wang and C. W. Shen, "Theresearch on control strategy of wind power generation system", Electrical Drive Automation, vol. 28, no. 5, **(2009)**, pp. 1-5.

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