Active Power Filter Design by a Simple Heuristic Search

Thanatchai Kulworawanichpong, Kongpol Areerak, and Sarawut Sujitjorn

School of Electrical Engineering, Suranaree University of Technology
Nakhon Ratchasima, 30000, Thailand
sarawut@ccs.sut.ac.th

Abstract. This article proposes a new design method based on a simple heuristic technique to eliminate harmonic in power systems. It is called modified least compensation current control (MLC) method. The effectiveness of the method is verified by comparison studies among the d-q axis, the synchronous-detection, and the sliding-window Fourier analysis methods, respectively. All are regarded as group-harmonic identification methods. The results confirm the effectiveness of our proposed MLC method.

1 Introduction

At present, electronic converter technology is vital for industries. No one can deny the fact that the converter's switching function pollutes the power system quality. This kind of pollution is often termed harmonic. It causes degraded performance of machines [1], failure of protective devices [2,3], short life-time of lamps [4], etc. Various types of filters have been used to eliminate harmonic [5,6].Among those, active filters having a common structure as shown in fig. 1 are very efficient.

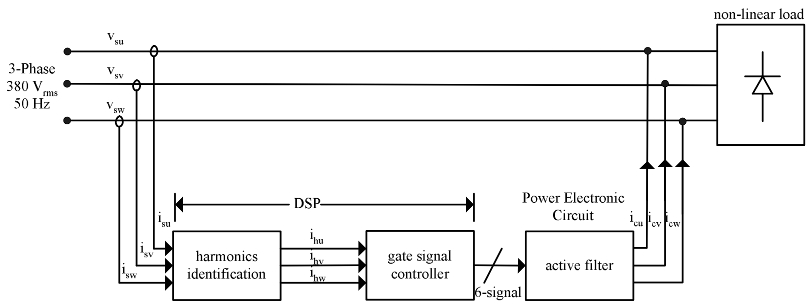


Fig. 1. Structure of active power filters

To provide proper current injection to the system to eliminate harmonic, the active filter needs the information of harmonic contents. It thus requires a harmonic identifier as its essence.

To date, the following group-harmonic identification methods have been accepted about their effectiveness: the d-q axis (DQ), the synchronous-detection (SD), and the sliding-window Fourier analysis (SWF) methods [7-9], respectively. We thus conducted our comparison studies among them as our results reported herein. Section 2 of this article describes our proposed new method for harmonic elimination so called MLC method. Its structure possesses a nonlinear element whose characteristic needs to be identified by a simple heuristic search. Sections 3 and 4 provide the results, discussions, and conclusions, respectively.

2 MLC Method for Harmonic Elimination

Zhou and Li, 2000 [10], introduced the approach of injecting the filter's current into the system to compensate for harmonically contaminated load current. It results in a sinusoidal supply current of 50 Hz frequency. To achieve this, the prediction of the fundamental component must be accurate. It may further require an accurate phase detection for unity power factor control. We propose a modified method based on Zhou and Li's approach so called modified least compensation current control (MLC) method for harmonic elimination. Our method is represented by the diagram in figure 2. Fundamentally, it can be viewed as the simplest structure shown in figure 3.

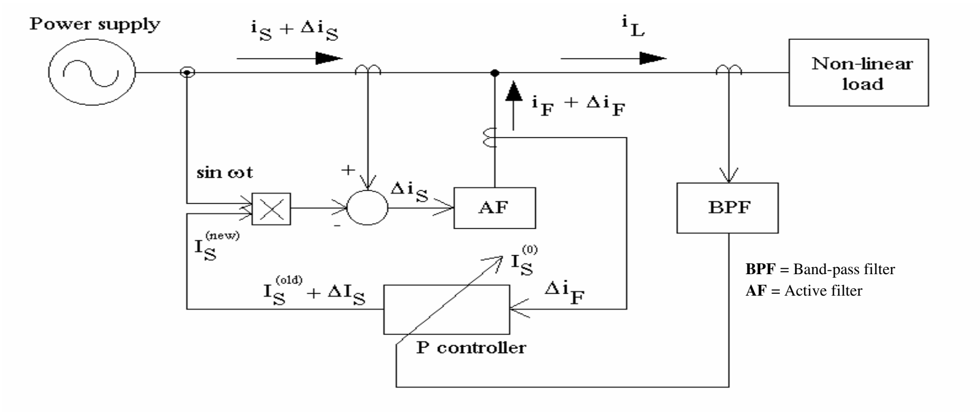


Fig. 2. Power active filter using MLC method

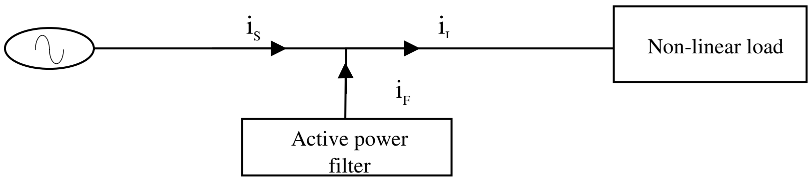


Fig. 3. Simple diagram representing a power system

Equation (1) describes the relationship of the currents, in which i_S is supply current, i_L is load current, and i_F is filter current. It is expected that the supply current contains only the fundamental component as given in equation (2), where I_S is the magnitude, and $_S$ is the frequency of the fundamental, respectively. We accept the fact that the prediction error can occur. So, the equation (1) when the prediction error (Δi_S) is taken into account can be rewritten as equation (3).

$$i_S = i_L - i_F \tag{1}$$

$$i_S = I_S \sin \omega_S t \tag{2}$$

$$(i_S + \Delta i_S) = i_L - (i_F + \Delta i_F) \tag{3}$$

Hence,

$$\Delta i_S = \Delta I_S \sin \omega_S t = -\Delta i_F \tag{4}$$

The amount of compensating current injected into the system at any instant ($t=T_{samp}$) is

$$\Delta i_{F,T_{samp}} = -\Delta I_S \sin \omega_S T_{samp} \tag{5}$$

that is

$$\Delta i_{F,T_{samp}} \propto \Delta I_S \tag{6}$$

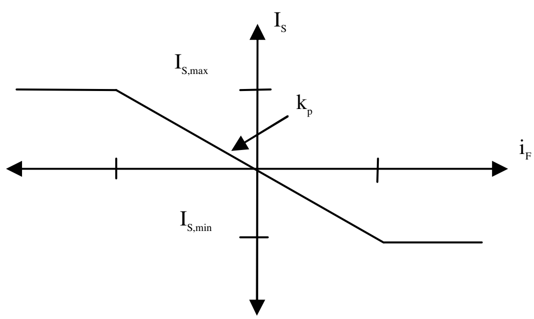


Fig. 4. P-controller characteristic

Control of compensating current injection can be achieved by using a P-controller having saturation characteristic as shown in figure 4. Due to the non-linear loads, and the stability requirement, the search for the proper characteristic of the controller is an important issue to be discussed in the following section.

- **Simple heuristic parameter tuning for the MLC method**

$I_{S,max}$ and k_p are two key parameters resulting in the shape of the compensated current. In this work, only k_p is varied while $I_{S,max}$ is kept constant. The adjustment is based on a simple heuristic search technique, which can be described by the following rule.

IF i_S *is not purely sinusoidal* **THEN** k_p *is reduced by the factor of 2*

To demonstrate this technique, the compensated waveforms resulting from the above IF-THEN rule are shown in figure 5.

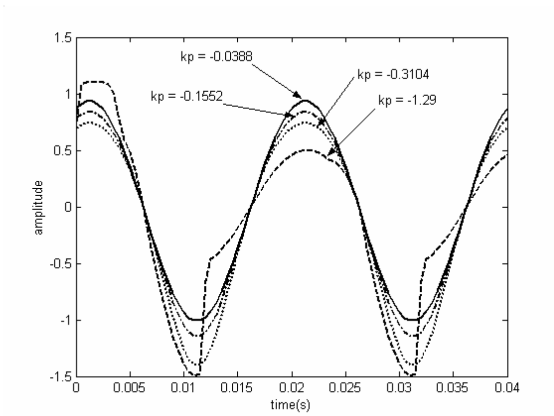


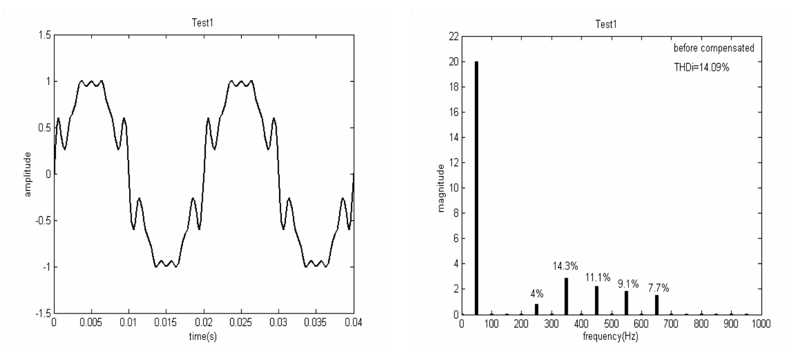
Fig. 5. Compensated waveforms with k_p adjustment

3 Simulation Results

This section describes two test case scenarios through computer-based simulation as follows.

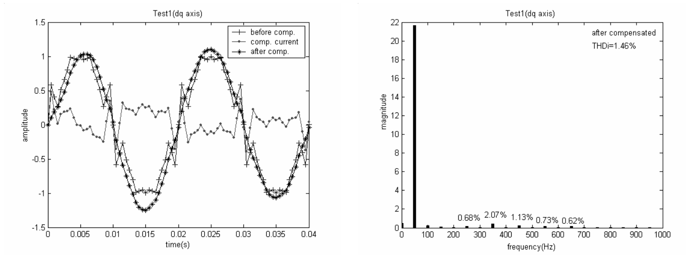
3.1 Test1

Figure 6 gives a waveform for the first test together with its spectrum. The four candidates are employed to eliminate harmonic components. The results show that the total

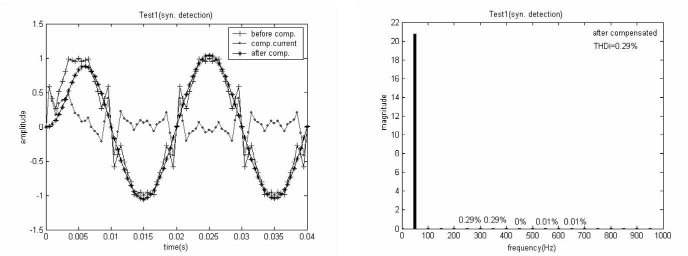


(a) time-domain waveform (b) spectrum

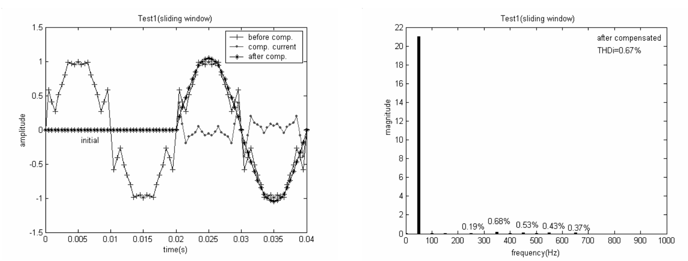
Fig. 6. Current waveform for Test 1



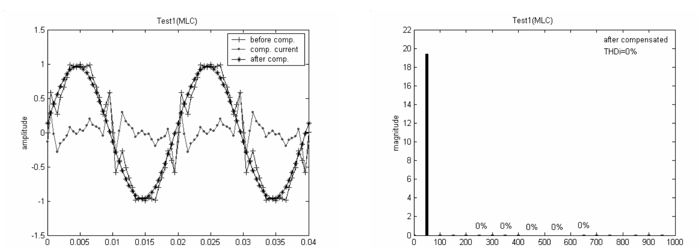
(a) waveforms and spectrum resulting from the DQ method



(b) waveforms and spectrum resulting from the SD method



(c) waveforms and spectrum resulting from the SWF method



(d) waveforms and spectrum resulting from the MLC method

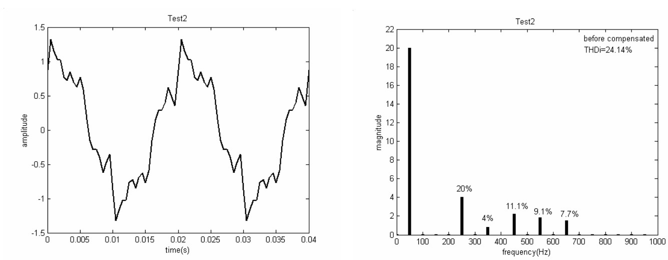
Fig. 7. Compensated currents for Test 1

harmonic distortion of the compensated current, THDi, is 1.46%, 0.29%, 0.67% and 0% for the SD, DQ, SWF and MLC methods, respectively. In addition, the spectrum of each case is shown in figure 7.

As can be seen, the disadvantage of the SD, DQ and SWF methods is that they have the delay within the first cycle, the current is fully compensated for without any delay via the proposed method.

3.2 Test2

Figure 8 gives a waveform for the second test together with its spectrum. The four candidates are employed as the first test. The results show that the total harmonic distortion of the compensated current, THDi, is 3.13%, 0.67%, 8.04% and 0% for the SD, DQ, SWF and MLC methods, respectively. For this case, the compensated current resulting from the SWF method does not pass the IEEE19-1992 standard [11]. In addition, the spectrum of each case is shown in figure 9.



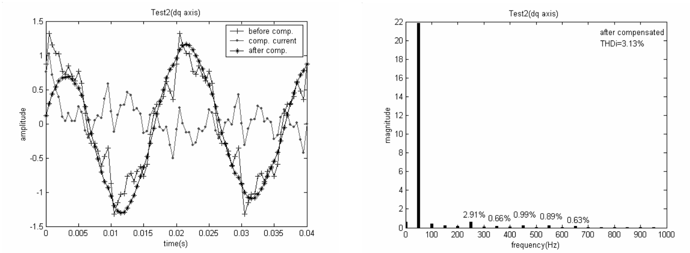
a) time-domain waveform (b) spectrum

Fig. 8. Current waveform for Test 2

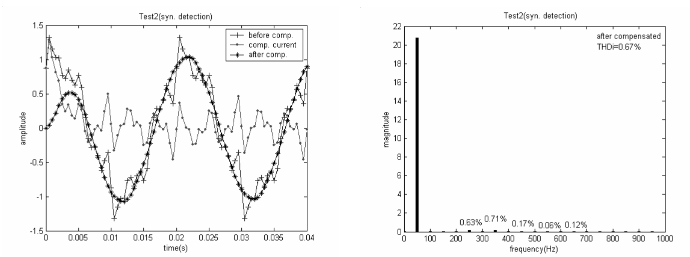
As the first test, the disadvantage of the SD, DQ and SWF methods is the delay for compensating the current at the first cycle. In contrast, when the MLC method is used, the current is compensated for with no delay and the compensated waveform is purely sinusoidal.

4 Conclusions

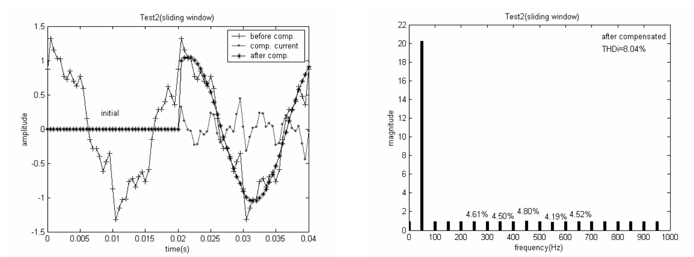
The MLC method proposed in this paper has the ability to fully eliminate all harmonic components. It is fast and simple to be used in real-time. Also, when compared with the responses compensated by the SD, DQ and SWF methods, the proposed method gives the best transient characteristic. However, the use of this method depends upon the P-controller design. It requires a careful parameter setting in such a way that the compensated current must be purely sinusoidal as its reference. Therefore, in this paper, the parameter setting is tuned through a simple heuristic search technique. With this technique, the proportional gain of the P-controller can be adjusted appropriately to guarantee the perfect compensation.



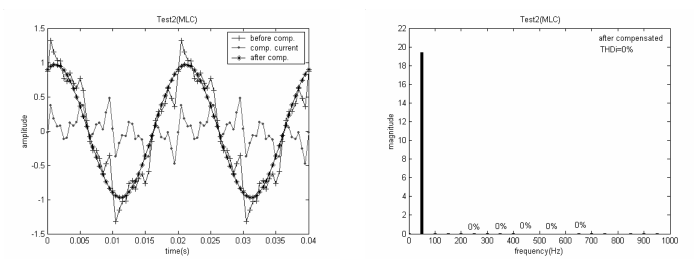
(a) waveforms and spectrum resulting from the DQ method



(b) waveforms and spectrum resulting from the SD method



(c) waveforms and spectrum resulting from the SWF method



(d) waveforms and spectrum resulting from the MLC method

Fig. 9. Compensated currents for Test 2

5 Acknowledgement

The financial support from Suranaree University of Technology is greatly acknowledged.

References

1. IEEE Standard 141-1993: Harmonics in Power Systems.
2. Brozek, J.P.: The Effects of Harmonics on Overcurrent Protection Devices, IEEE Industry Applications Society Conference, 2 (1990) 1965-1967
3. Ho, J.M. and Liu, C.C.: The Effects of Harmonics on Differential Relay for a Tranformer, IEE International Conference and Exhibition on Electricity Distribution (CIRED), 2 (2001)
4. Wakileh, G.J.: Power Systems Harmonics, Springer-Verlag, 2001
5. Lin, B.R., Yang, B.R. and Tsai, H.R.: Analysis and Operation of Hybrid Active Filter for Harmonic Elimination, Electric Power Systems Research, 3 (2002) 191-200
6. Jung, G.H. and Cho, G.H.: New Active Power Filter with Simple Low Cost Structure without Tuned Filters, IEEE Power Electronics Specialists Conference (PESC'98), 1 (1998) 217-222
7. Takeda, M., Ikeda, K., Teramoto, A. and Aritsuka, T.: Harmonic Current and Reactive Power Compensation with an Active Filter, IEEE Power Electronics Specialists Conference (PESC '88), 2 (1988) 1174-1179
8. Chen, C.L., Lin, C.E., Huang, C.L.: The Reference Active Source Current for Active Power Filter in an Unbalanced Three-Phase Power System via the Synchronous Detection Method, IEEE Instrumentation and Measurement Technology Conference (IMTC/94), 2 (1994) 502-505
9. EI-Habrouk, M. and Darwish, M.K.: Design and Implementation of a Modified Fourier Analysis Harmonic Current Computation Technique for Power Active Filter Using DSPs, IEE Proc.-Electr. Power Appl., 1 (2001) 21-28
10. Zhou, L. and Li, Z.: A Novel Active Power Filter Based on the Least Compensation Current Control Method, IEEE Trans. on Power Electronics, 4 (2000) 655 – 659
11. EEE Standard 519-1992.