CHEMICAL ENGINEERING TRANSACTIONS

VOL. 51, 2016

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

ISBN 978-88-95608-43-3; **ISSN** 2283-9216

DOI: 10.3303/CET1651074

The Design of Hybrid Active Power Filter based on Harmonics Detection and Its Simulation Research

Zhengyou Ma

Department of Electrical Engineering, Sichuan College of Architectural Technology, Deyang, Sichuan 61800, China
mazhengyou@sohu.com

This paper puts forward a design method of hybrid active power filter which is based on harmonics detection and identifying. Firstly the paper analyzes damage and causes of the harmonics, then several solutions to harmonics problems are devoted to harmonic suppression. The hybrid active power filter, which combines active power filter, passive power filter and generalized integrators, and which has their both respective merits, leading the development of electric reliability and quality. According to minimum current principle of harmonic compensation, the compensation performance of hybrid active power filter in power distribution system has been analyzed and verified by Matlab simulation, and the stable current experimental results shows this power filter in this paper is going quite well effect on harmonic compensation in circuit, and this hybrid filter which connects in series active filter and passive filter improves the compensations performance remarkably, meanwhile avoiding the expensive initial cost.

1. Introduction

With the rapid development of the national economy, the power quality and its service reliability have become growing concerns in the field of energy conversion and utilization in recent years. Especially with the increasing sensitivity and precision of electronic equipment and automated controls, there are several defects that will cause the electrical power system breakdown, and there are also some voltage fluctuations that will seriously affect the performance of the system. These reasons which cause voltage fluctuations are always harmonic distortion, surges and spikes, and momentary disruptions. Among them, harmonic distortion is voltage or current frequencies riding on top of the normal sinusoidal voltage and current waveforms, and the harmonics are the main reason which will cause overheating of transformers and wiring, nuisance breaker trips, and reduced power factor (Daniel, et al., 2013).
When the current is switched on or off each time, harmonics are created by this current pulse. Because of these resistive and reactive loads, this current pulse does not vary smoothly with voltage, so these “nonlinear loads” will generate a spectrum of harmonic frequencies, which includes the fundamental frequency and its multiples (Moran, et al., 1995). In China the fundamental frequency of the AC is 50Hz, as shown in figure1, the combined waveform shows the effect of multiples of harmonic on the fundamental frequency of current, and there are 5^{th}, 7^{th}, 11^{th}, and 13^{th} harmonics in the combined waveform, and according to the past research, the third harmonic which the frequencies is 150Hz in circuits system plays the most serious interference in the electric power system, and which is created by single-phase loads such as telephone, fax and computers (Tang Y. et al. 2012).
The harmonics in distribution circuit do not always causes problems in case of modern electronic devices will contain some frequencies of harmonics, but the greater the power drawn by these modern devices or other nonlinear loads, the greater level of voltage distortion which is caused by harmonics (Dash, et al., 2016). The table 1 shows the potential defects which attribute to harmonics in the electric power system. In order to suppress the harmonics, at the present stage there are several ways to deal with harmonics problems through prevention, in this paper a new hybrid active power filter based on Harmonics Detection is put forward to harmonics suppression, and with the help of Matlab simulation, the active power filter will be a better opportunity for harmonics suppression and place a very high premium on power quality and reliability.

Please cite this article as: Ma Z.Y., 2016, The design of hybrid active power filter based on harmonics detection and its simulation research, Chemical Engineering Transactions, 51, 439-444 DOI:10.3303/CET1651074

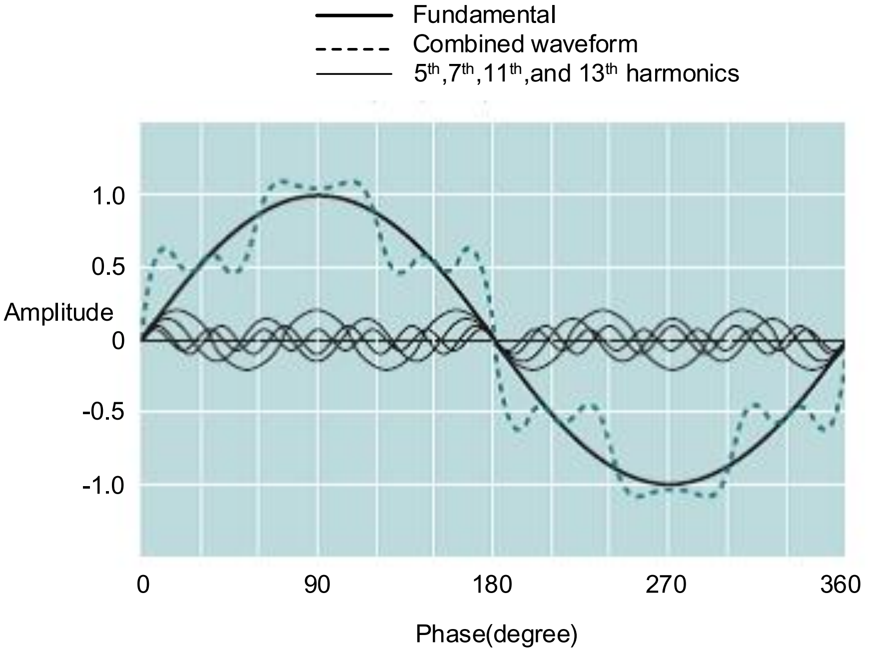


Figure 1: Effect of harmonics combined in normal current

Table 1: The potential defects of harmonics

No.	The potential defects of harmonics
1	Malfunction of sensitive and nonlinear equipment and device
2	Overheated phase conductors, transformers and panels
3	Flickering lights and super high neutral currents
4	Premature failure of transformers and uninterruptible power supplies
5	Reduced power factor and Reduced system capacity
6	Random tripping of circuit breakers

2. Harmonics detecting and identifying

The best way to eliminate harmonics is insulation, which is choosing equipment and installation practices that minimize the level of harmonics in the circuit and portion of facility. The harmonics problem will be solved by these methods, such as adding additional circuits to help isolate the sensitive equipment from what is causing the harmonic distortion (Wu, et al., 2015).. Another way to suppress the harmonics is passive filter (also called LC filter), which is composed of inductance, capacitance and resistance, a passive filter shows the low impedance at tuned frequency to absorb current harmonic and has a good compensation performance. But the passive filter has the disadvantage of susceptible to the the electric power system and the characteristic change due to aging, and the passive filter always has fixed parameters, and this character can't adapted for the complex and changeable situation. As one of the key technologies in combating harmonic distortion and improving the power quality, active power filter (APF) has become a trending research emphasis in power electronics technology, and the active power filter overcomes these disadvantages of the passive filter, and it can provide reliable and flexible compensation, but it also has its shortcoming-high operation cost and low rate of quantity and price (Biricik, et al., 2015).. Table 2 shows the best application and its shortcoming of vvarious solutions of harmonics suppression.

From table 2, hybrid active filter composed of passive power filter connected in series to the active power filter improves the compensation performance of passive filter remarkably, give more flexibility and reliability to power device, and the hybrid active filter in this paper will comfortable for high-power system avoiding the expensive initial cost.

Table 2: Solutions of harmonics suppression

Solution	Best application	Shortcoming
Isolation Transformer	Where sources of harmonics are on separate branches from harmonics-sensitive equipment.	Isolates but does not remove the harmonics problem
Passive filter	For circuits that include three-phase loads, where there are only minor voltage imbalances between phases.	Lower-cost than active filters, but requires analysis and a trial-and-error approach
Active filter	For circuits that include three-phase loads; voltage imbalances between phases can be present	Adapts to changes in system but the cost is too much
Hybrid active filter	Almost every working occasion can be comfortable	Give more flexibility and reliability to power device

3. Minimum current principle of harmonic compensation

The hybrid active filter consists of active power filter (APF), passive power filter, three-phase PWM voltage inverter (pulse width modulation) and coupling transformer. As shown in figure2, the active power filter and passive power filter are connected in series to voltage inverter through coupling transformer. In this system the APF prevents the harmonic current into hybrid active filter, and it plays a voltage inverter controlling role in this circuit.

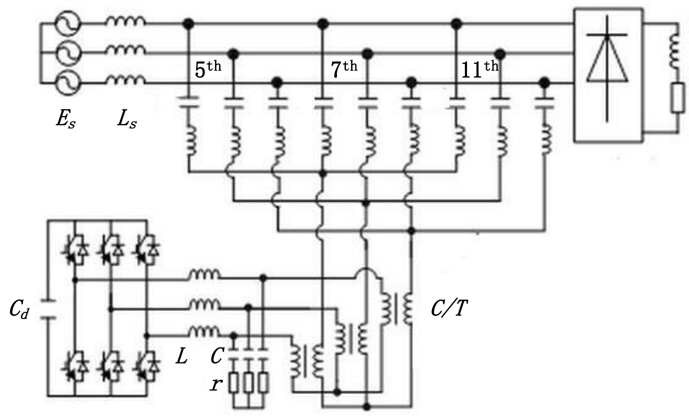


Figure 2: The configuration and structure of hybrid active filter

When the feedback control is applied to the active power filter, the figure3 shows that the minimum harmonics compensation process is operated by the single-phase equivalent circuit. In order to suppress current harmonic in the circuit, the active power filter is considered as a controlled voltage source, and this voltage is VAPF, and the voltage value of this filter is shown in Eq(1).

$$VAPF = K \ I_{sh} \tag{1}$$

In Eq(1), K is the harmonic compensation gain, I_{sh} is the load harmonic current. Supposing utility voltage is pure sinusoidal, the ration between the utility harmonic current and the load harmonic current is obtained, which can be used to denote the filtering characteristics of hybrid active power filter.

The Eq(2) shows the characteristics of hybrid active power filter. In this equation, Z_F is the impedance of passive filter, I_{Lh} is the load harmonic current, Z_S is the system impedance. Associate with Eq(1) and Eq(2), K is the resistance to damp resonance between Z_F and Z_s. Choosing the larger value of K will significantly reduce the harmonic content in the actual current, however, the larger value of K will increase the rated power of the active filter.

$$\frac{I_{sh}}{I_{lh}} = \frac{Z_F}{Z_S + Z_F + K} \tag{2}$$

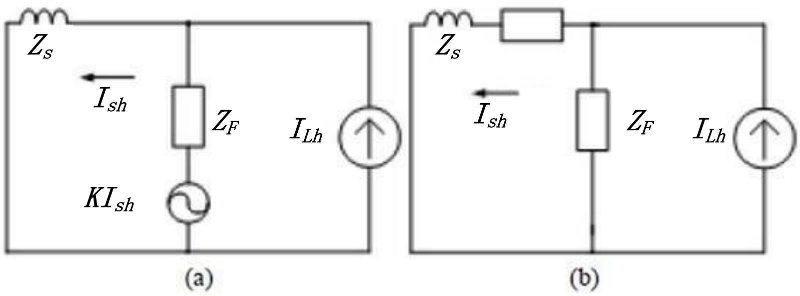


Figure 3: The single-phase equivalent principle of harmonic compensation

4. The performance of hybrid active power filter in power distribution system

4.1 Test environment and test parameters

The test of harmonic suppression of the hybrid active power is depended on a three-phase shunt power laboratory, which is implemented and tested in the compensation of a six-pulse uncontrolled rectifier. As shown in figure4, the VSI voltage contains a capacitor bank, and the parameters of the capacitor bank is 6800 μF and DC-450V, and a dual DSP (TMS320C32 and TMS320F240) and CPLD circuit are adopted in this digital control system, which sampling period is 200 μs. The detail parameters of the test power laboratory are shown in table3.

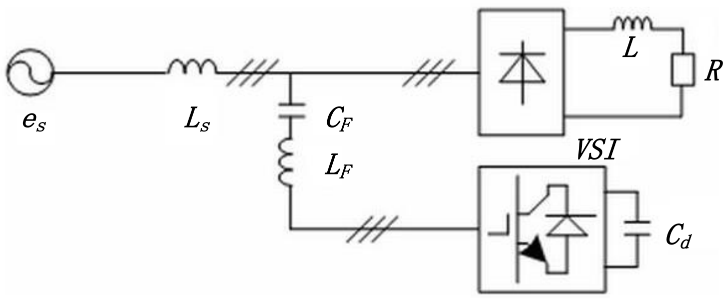


Figure 4: The environment of performance test for harmonic suppression

Table 2: Test parameters of harmonic suppression in laboratory

No.	Parameters	Value
1	Utility impedance	0.5mH
2	Utility three-phase voltage	380V
3	DC-voltage	200V
4	C_F	50 μF
5	L_F	4mH

Owing to the single LC filter of 7^{th} of harmonic suppression, there are several amount of harmonic such as 5^{th}, 11^{th} and 13^{th} of remaining harmonics in the circuit. Therefore, the PI current controller which is made up of generalized integrators is used as the remaining harmonics suppression. The PI current controller in stationary frame is depicted in figure5. In figure5, i_s* is the grid current reference, K_i is the integral coefficient, and the VAPF is the violate reference. This figure is use to realize the digital generalized integrators.

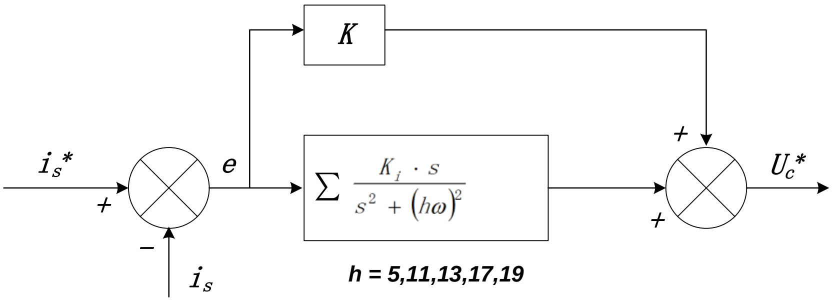


Figure 5: The structure of the PI current controller

For reducing the computation time of harmonics suppression, the generalized integrators are implemented by iterative arithmetic. When generalized integrators are used, the harmonic attenuation rate is shown in Figure 6. Figure 6 illustrates that the 5th, 11th, 13th, 17th and 19th harmonic current are eliminated effectively by reason of generalized integrators in this circuit, and the stable experimental results for harmonic compensation has been also shown in figure 6.

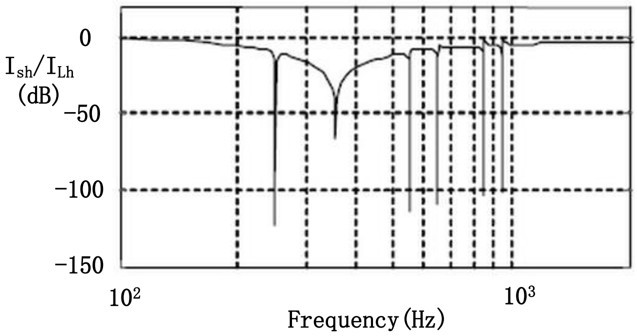
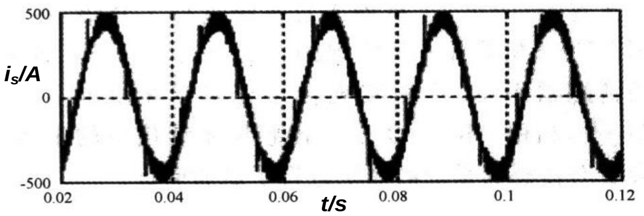
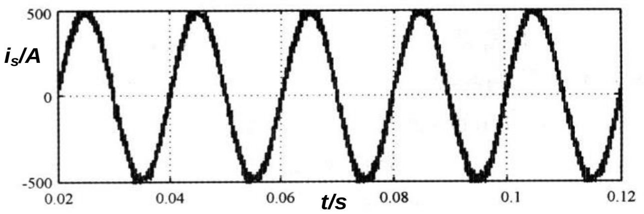


Figure 6: The harmonic attenuation rate under generalized integrators

In order to verify the filtering effect, the Matlab software is used to build the simulation model of the active filter, and the simulation waveform is shown in Figure 7. From figure 7 the active filter is used to compensate harmonics and reactive current, which can compensate the harmonic and reactive current in the load at the same time. This figure shows that the current waveform has a wonderful compensation effect with the help of the hybrid active power filter.



(a) The fundamental current waveform



(b) The current waveform after harmonic compensation

Figure 7: The difference current waveforms between the fundamental current and compensation current

5. Conclusions

This paper puts forward a design method of the hybrid active power filter based on harmonics detection and minimum current principle of harmonic compensation, and on the basis of damage and causes of the harmonics, several solutions to harmonics problems are analyzed to harmonic suppression, such as prevention method, passive filter, insolation transformer and active harmonic filter. In addition to these suppression measurements, many power-monitoring devices are now commercially available from a variety of manufacturers to measure and record the harmonic levels. After taking the appropriate methods to determine the harmonic levels, the best solution to harmonic suppression should be chose from the harmonic source and cause.

Due to the characters of harmonics composition and the consideration of high rate of quantity and cost, a hybrid active power filter method which is based on harmonics detection has been applied to harmonics suppression. The hybrid active power filter is composed of active power filter, passive power filter and in series of generalized integrators. Then according to minimum current principle of harmonic compensation, the compensation performance of hybrid active power filter in power distribution system has been analyzed and verified by Matlab simulation in laboratory.

The stable current experimental results shows this power filter in this paper is going quite well effect on harmonic compensation in circuit, and this hybrid filter which connects in series active filter and passive filter improves the compensations performance remarkably, meanwhile avoiding the expensive initial cost. This hybrid active power filter in this paper has their both respective merits of the active power filter and the passive power filter, leading the development of electric reliability and quality.

Reference

Biricik S., Redif S., 2014, Real-time control of shunt active power filter under distorted grid voltage and unbalanced load condition using self-tuning filter, let Power Electronics, 7(7): 1895-1905. Doi: 10.1049/iet-pel.2013.0924

Daniel P. Palomar., Convex Optimization in Signal Processing and Communications, Science Press, Beijing.

Dash SK., Panda G., Ray PK., Pujari SS., 2016, Realization of active power filter based on indirect current control algorithm using Xilinx system generator for harmonic elimination, International Journal of Electrical Power & Energy Systems, 74: 420-428. Doi: 10.1016/j.ijepes.2015.08.010

Feng F., Ai C., Xu H., Cui Z., Gao C., 2015, Research on the condition model of drilling fluid non-retention in eccentric annulus, 33(1): 9-16.

Moran L., Diaz M., Higuera V., 1995, A three-phase active power filter operating with fixed switching frequency for reactive power and current harmonic compensation, IEEE Transactions on Industrial Electronics, 42(4): 402-408. Doi: 10.1109/41.402480

Singh S.N., Singh D.K., 2015, Study of combined free convection and surface radiation in closed cavities partially heated from below, International journal of heat and technology, 33(2):1-8. Doi: 10.18280/ijht.330201

Tang Y., Loh PC., Wang P., Choo FH., 2012, Generalized Design of High Performance Shunt Active Power Filter With Output LCL Filter, IEEE Transactions on Industrial Electronics, 59(3): 1443-1452. Doi: 10.1109/TIE.2011.2167117

Wu L., Li T., Chen Z., Li H., 2015, A new capacitive borehole tiltmeter for crustal deformation measurement and its performance analysis. International Journal of Mining Science & Technology, 25(2): 285-290. Doi: 10.1016/j.ijmst.2015.02.018

Xiao Z., Deng X., Yuan R., Guo P., 2014, Shunt active power filter with enhanced dynamic performance using novel control strategy, let Power Electronics, 7(12):3169-3181.

Zeng Z., Yang JQ., Chen SL., Huang J., 2014, Fast-Transient Repetitive Control Strategy for a Three-phase LCL Filter-based Shunt Active Power Filter, Journal of Power Electronics, 14(2):392-401.