

Application of Active Power Filters to compensate reactive power

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ABSTRACT: Active power filters (APFs) play an important role in elimination of power system harmonics. According to these structures, they can be used to compensate of network reactive power. In this paper, reactive power compensation along with removing of network harmonics by APF has been studied. For this purpose, an active power filter has been simulated using hysteresis current control (HCC) method in the PSIM software. Simulations have been accomplished for different operation modes such as harmonics elimination, reactive power compensation and instantaneously harmonics elimination along with reactive power compensation. Obtained results have shown that by a suitable planning of APFs can be used their capabilities in the reactive power compensation application.

Keywords: Active power filter, harmonic compensation, reactive power compensation and AC/DC converter.

INTRODUCTION

The growing number of power electronics-based equipment has produced an important impact on the quality of electric power supply. Nonlinear load such as AC/DC converter, arc furnace, switching power supplies have been significantly growth in the power system and smart grid. These kinds of loads may inject harmonic current into the power system; leading to distort network voltage and also to increase total losses of network (Chang and Chang JULY 2000). Passive filters are the first solution to eliminate these harmonics, however; they have demerits of fixed compensation, large size, and resonance (harmonic amplification can be occurred). Alternatively, the active filters are used to eliminate the power system harmonics to the range of harmonic standards such as IEEE-519 (Singh and Al-Haddad Oct. 1999).

Active power filters, have been widely used to suppress harmonics of network. In fact the APF injects harmonic current to point of common coupling (PCC) equal but opposite with harmonic current of the nonlinear load in order to neutralize PCC harmonic current.

Different studies have been done in harmonics compensation among which active power filters can be mentioned that are widely used in distribution system and are able to remove all harmonics to improve power factor and unbalance. In recent decades, different structures for active filters have been presented such as combined filters (Kim and Enjeti 2002; Wu, Tong et al. 2004), series and parallel active filters (Fujita and Akagi 1991; Aredes, Hafner et al. 1997; Kim, Kim et al. 2004; Lin and Lee 2004; Miret, DeVicuna et al. 2004; Sladic, Odavic et al. 2004). Moreover, different controlling methods in frequency domain (Sonnenschein and Staudt 1998), and time domain such as notch filters, D-Q theory with synchronous reference, synchronous current tracking method (Singh, Al-Haddad et al. 1998; Li, Zhuo et al. 2004) and instantaneous power theory (Takeda, Ikeda et al. 1988; Komatsu and Kawabata 1997; Afonso, Freitas et al. 2003) are presented. According to what has been mentioned active filter efficiency in reactive power injection to network as well as harmonic elimination has been investigated.

To do, so an active filter has been simulated by PSIM software. Controlling method used for this filter is a current hysteresis controlling way, which is simple and cheap. Filter effectiveness in different injection modes of reactive and harmonic power have been studied.

Principle of Hysteresis Current Control

This section presents the principle of Hysteresis Current Control (HCC) technique for single-phase active power filter that is shown in Fig. 1. The APF can operate in both rectifying (rectifier) and inversion (inverter) modes. A dead band with an upper and lower boundary current reference is used to generate the switching signals. The output current is regulated by comparing actual current with a reference current and the difference between the two current (ΔI) is used to turn on or off the switch. Regardless of where the current starts, switching takes place as soon as a boundary is encountered. Initially, in Fig. 1, the switches S_1 and S_2 are turns on and S_3 and S_4 are turns off because the output current of the AC/DC converter is below the lower (turn-on) boundary. The output current then rises at a rate limited only by the inductor, the capacitor, and the load. The switches S_1 and S_2 then turn off and S_3 , and S_4 are turns on. When the output current crosses the upper boundary and it remains off until the output current falls below and cross the lower boundary where the switch is turned on again. The variation of switch S_1 is shown in Fig. 2.

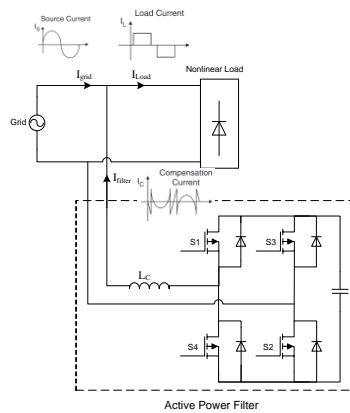


Figure 1. Typical shunt APF

Hysteresis control in principle eliminates the output variations and the system will stay close to the desired output current even if the input voltage, the load, or the component values change. Hysteresis control also provides an immediate response to dynamic disturbances. The control circuit is very simple and relatively straightforward to design and physically implement.

In this method, output current between two upper and lower band current is varied. In fact, the output current should be between two sinusoidal currents. In this method, hysteresis band is remained fixed. According to Fig. 2, the following equation can be written:

$$I_{ref} = I_m \cdot \sin(\omega t) \tag{1}$$

$$I_{ref_up} = I_{ref} + \frac{\Delta I}{2} \tag{2}$$

$$I_{ref_down} = I_{ref} - \frac{\Delta I}{2} \tag{3}$$

Where, ΔI is hysteresis bandwidth. The point, which should be mentioned in this way, is that according to Fig.2, switching frequency is changeable. Moreover, this and this matter should be taken into consideration in switches selection and loss calculation. In other words, by increasing hysteresis bandwidth, switching frequency decreases.

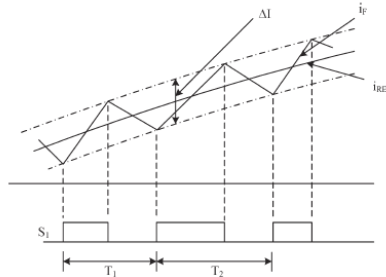


Figure 1. Filter current control with Hysteresis control method

Active Filter Operation modes

An active filter due to using semiconductor technology in its structure have many capabilities. For instance, if an active filter is connected to an energy source or a battery in DC link, it can transfer battery energy to network. Hence four operating modes are considered which are as:

- Mode 1: active power injection
- Mode 2: reactive power injection
- Mode 3: distortion power injection (harmonic cancelation)
- Mode 4: instantaneously active, reactive power injection and harmonic cancelation

Operation of each mode will be explained. It should be mentioned that network voltage is expressed as following equation:

$$V_{grid} = V_m \cdot \sin(\omega t) \tag{4}$$

Mode 1: Active power injection

In this mode, sinusoidal reference current is considered in phase a network voltage and active current is injected to the network. In this mode, reference current is considered according to this equation:

$$I_{ref} = I_m \cdot \sin(\omega t) \tag{5}$$

Mode 2: Reactive power injection

One of the network requirements is reactive power. Providing locally reactive power has some advantages such as voltage profile improvement, loss reduction and so on. Therefore, if active power filter is used in reactive power injection mode, we can benefit advantage of locally providing reactive power. In this case, the reference current similar to mode 1 is considered sinusoidal. But it is not in phase with network voltage. Reference current is considered as:

$$I_{ref} = I_m \cdot \sin(\omega t \pm \varphi) \tag{6}$$

Where “+” is for capacitive reactive power and “-” is for inductive reactive power.

Mode 3: Harmonic cancelation

The main duty of active power filters is elimination of network harmonic. In this mode, active filter provides current harmonic component requirement for load current and it presents harmonic current absorption from network. In this case, reference current is equal to sum of harmonic components requirement for load. Hence, load current harmonic component should be identified and they should be produced by active filter. Reference current in this case is:

$$I_{ref} = \sum_{n=2}^N I_{m,n} \sin(n\omega t \pm \varphi_n) \tag{7}$$

Where N is the highest order load current harmonics and $I_{m,n}$ is amplitude of n th component of load current. However, some of these components amplitudes may be zero. Therefore, in this case this component will not be produced by active filter.

Mode 4: Instantaneously active, reactive power injection and harmonic cancelation

In this mode, each of three active, reactive and harmonic current can be injected to network. The reference signal is considered sum of fundamental sinusoidal waveform that is not in phase with network voltage (the difference between filter output current and network voltage angle determine the amount of injected reactive power) and component of harmonic sinusoidal current with different amplitudes and angles.

$$I_{ref} = \underbrace{I_{m1} \cdot \sin(\omega t \pm \phi_1)}_{P,Q} + \underbrace{\sum_{n=2}^N I_{m,n} \sin(n\omega t \pm \phi_n)}_D \quad (8)$$

In this case, the first term of (8), shows active and reactive current, which the amplitude of each current is, determine by ϕ_1 . Furthermore, the second term is distortion power, which is needed for load harmonic eliminating.

Simulation result

The filter parameters are shown in Table 1. To investigate the efficiency of active power filter in the harmonic cancelation, reactive power compensation and injecting of active power to network, a sample active filter according to Fig. 3 is simulated by PSIM, which obtained results are investigated. It is noted that the simulation has been done for all of four operation modes of active filter, which is described in section 4.

Table 1. Filter parameters

parameter	value
V_{grid}	220
R_1	10 k Ω
R_2	1 k Ω
R_f	20 k Ω
L_c	7 mH
I_n	10 A

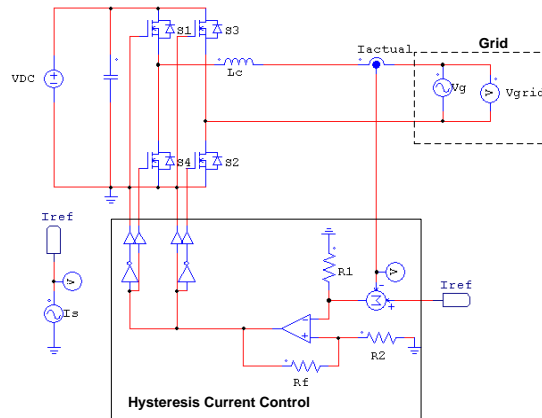


Figure 3. Modeling of Filter with hysteresis current control in PSIM

Mode 1: Active power injection

In this operating mode, reference current is considered as:

$$I_{ref} = 10 \cdot \sin(2 \times \pi \times 50t) \quad (9)$$

Reference current and output current waveforms in this case are shown in Fig. 4. According to this figure, injecting current follows reference current well and injects active power to network. Instantaneously active and reactive power is shown in Fig. 5. In this mode, only active power is injected to the network. As a result, reactive power is equal to zero.

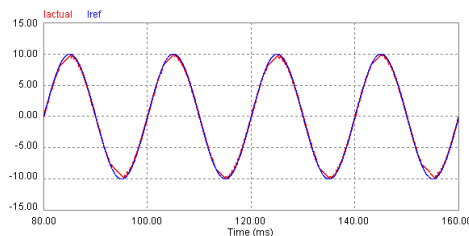


Figure 4. Filter output current and reference current in the active power injection mode

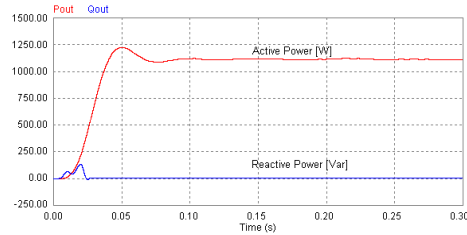


Figure 5. Active and Reactive power injected to grid in the active power injection mode

Mode 2: Reactive power injection

Reference current for mode 2 is considered as:

$$I_{ref} = 10 \cdot \sin(2 \times \pi \times 50t + \pi/2) \quad (10)$$

The reference current and output current for this mode are illustrated in Fig. 6. It is also viewed from this figure that injected reactive current follows reference current well.

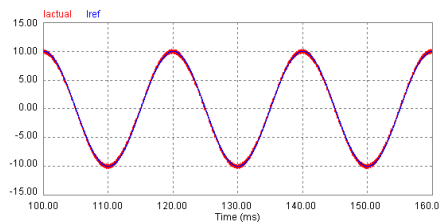


Figure 6. Filter output current and reference current in the reactive power injection mode

Instantaneously active and reactive power is shown in Fig. 7. According to this figure, active power is equal to zero and reactive power is very high in comparison with active power. In this case, regarding the ϕ_1 difference, active current can be also injected to the network. For this purpose, ϕ_1 should be less than 90° . In Fig. 8, filter current and network voltage are shown. To better observation, current is 10 times higher and $\phi_1 = \pi/4$.

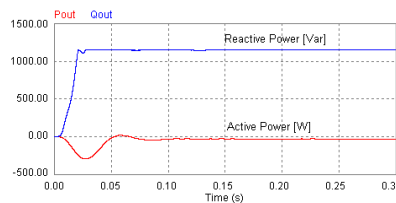


Figure 7. Active and Reactive power injected to grid in the reactive power injection mode with $\phi_1 = \pi/2$

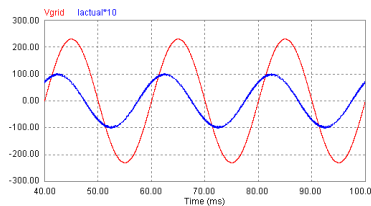


Figure 8. Filter output current and reference current in the active and reactive power injection mode

Instantaneously active and reactive power for $\phi_1 = \pi/4$ and injected active and reactive power to network by filter is shown in Fig. 9, active and reactive power are respectively equal to 735 W and -811 Var. Regarding $\phi_1 = \pi/4$, active and reactive power should be equal which is not true here because of converter losses.

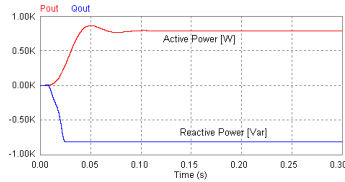


Figure 9. Active and Reactive power injected to grid in the active and reactive power injection mode with $\phi=1/\pi/4$

Mode 3: Harmonic power injection

The content harmonics in power systems are orders of $6k\pm 1, k=1, 2, 3, \dots$ so, in this operating mode the reference current is considered as:

$$\begin{aligned}
 I_{ref} = & 2.26 \sin(5\omega t) + 1.12 \sin(7\omega t) \\
 & + 0.904 \sin(11\omega t) + 0.645 \sin(13\omega t) \\
 & + 0.564 \sin(17\omega t) + 0.45 \sin(19\omega t) \\
 & + 0.408 \sin(23\omega t) + 0.345 \sin(25\omega t)
 \end{aligned}
 \tag{11}$$

Reference current and output current are shown in Fig. 10. According to this figure, injected harmonic current follows reference current properly. In this case, active and reactive power is not injected to the network because fundamental component of current does not exist in the reference current.

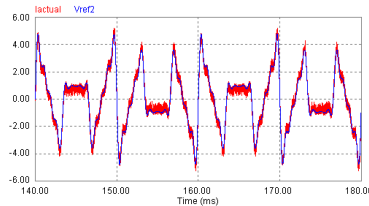


Figure 10. Filter output current and reference current in the harmonic cancelation mode

Mode 4: instantaneously injection of active, reactive and harmonic power

In this case, all three active, reactive and distortion power can be injected to the network. Reference current is considered as:

$$\begin{aligned}
 I_{ref} = & 10 \sin(\omega t - 30) + 2.26 \sin(5\omega t) \\
 & + 1.12 \sin(7\omega t) + 0.904 \sin(11\omega t) \\
 & + 0.645 \sin(13\omega t) + 0.564 \sin(17\omega t) \\
 & + 0.45 \sin(19\omega t) + 0.408 \sin(23\omega t) \\
 & + 0.345 \sin(25\omega t)
 \end{aligned}
 \tag{12}$$

In this mode, the output current is shown in Fig. 11. According to this figure, output current follows the reference current well.

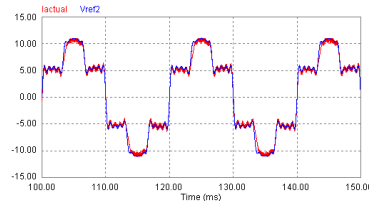


Figure 11. Filter output current and reference current in the harmonic cancelation with active and reactive power injection to grid mode

CONCLUSION

In this paper, it has been shown that by using semiconductor devices in active power filter structure and due to their capabilities, they can be used to improve capability of power system. One of important capabilities that can be obtained by very simple controlling and also by using cheap equipment is controlling active and reactive power. To investigate this matter, filter effectiveness for different operating modes were studied. It was shown that one filter can be injected an active, reactive and distorted power to network. The other results obtained from this study is

instantaneously injection of active, reactive and distortion power to network in order to eliminate the harmonics which can be obtained by selection of a suitable reference current.

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