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A Three Phase Shunt Active Power Filter for Currents Harmonics Suppression and Reactive Power Compensation

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Abstract: This study presents a three phase shunt active power filter for current harmonics suppression and reactive power compensation using the supply current as reference. The proposed APF has a simple control circuit; it consists of detecting the supply current instead of the load current. The advantages of this APF are simplicity of control circuits and low implementation cost. The simulation results show that the proposed APF can compensate the reactive power and suppress current harmonics with two types of non-linear loads.

Key words: Active power filter, current harmonics and reactive power compensation, PWM inverter, total harmonic distortion, power quality

INTRODUCTION

Power electronics converters are widely used in industrial equipment, such as diode or thyristor converter and frequency changers, DC and AC drives, etc. Such equipment presents a non-linear loads and generates large harmonic currents and low power factor. To solve these problems, many methods have been proposed.

A passive LC filter can be used to suppress the harmonic currents and a capacitor bank can be used to compensate the reactive power. However, passive filters have many disadvantages and they cannot solve these problems completely[1,2].

With remarkable progress in the capacity and switching speed of power semiconductors such as IGBT's and GTO thyristors, active filters consisting of voltage or current source PWM inverters have been studied[3] because they have the ability to overcome the disadvantages inherent in passive filters. In fact, many publications have already proposed innovative techniques to suppress the current harmonics produced by these non linear loads[4,5] and major researches have been carried out on control circuit designs for active filters. In study[6] , a review of active filters for power quality improvement is presented. In study[7] an improvement of power quality using adaptive shunt active filter is discussed.

In this study, a three phase shunt active power filter is proposed using the supply current as reference for harmonics suppression and reactive power compensation.

Basic theory: The simplified schematic of the three-phase shunt active power filter is represented in Fig. 1. The active power filter is three phase bridge bidirectional Pulse Width Modulated (PWM) inverter and a dc capacitor used as an energy storage element, the inverter operates as a current mode voltage source.

The non-linear load is a diodes rectifier feeding an RL, RC load or other non-linear loads. The active power filter supplies reactive power and harmonic power while the supply the real power to the non-linear load under steady state condition. Assuming the supply voltage is pure sinewave signal and it is represented as:

$$v_s(t) = V_s.\sin(\omega t) \qquad (1)$$

where
$v_s(t)$ instantaneous supply voltage;
V_s peak of supply voltage;
ω angular frequency of the supply;
t time.

The non-linear load current can be represented as:

$$i_L(t) = \sum_{n=1}^{\infty} I_n.\sin(n\omega t + \theta_n) \qquad (2)$$

where
$i_L(t)$ instantaneous load current;
I_n peak of the nth order harmonic of the load current;
θ_n phase of the nth order harmonic of the load current.

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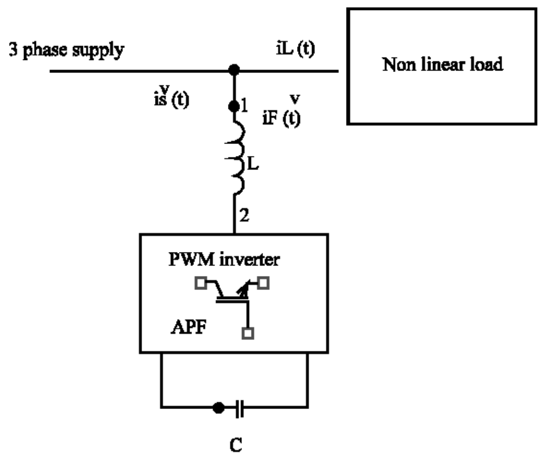

Fig. 1: Three phase shunt active power filter

The load current can be subdivided into the fundamental and harmonic components and it is represented as:

$$i_L(t) = I_n.\sin(\omega t + \theta_1)\sum_{n=2}^{\infty} I_n.\sin(n\omega t + \theta_n) \quad (3)$$

Where

I_1 Peak of the fundamental component of the load current;

θ_1 Phase of the fundamental component of the load current.

If the harmonic components are filtered out, the fundamental component of the load current is represented as:

$$i_{L1}(t) = I_1.\sin(\omega t+\theta_1) \quad (4)$$

The fundamental component in equation (4) can be subdivided into real component and reactive component

$$i_{L1}(t)= I_1\cos\theta_1.\sin(\omega t+\theta_1) + I_1\sin\theta_1.\cos(\omega t+\theta_1) \quad (5)$$

For the good performance of the active power filter, the supply current must be equal to the real component of the fundamental component of the load current

$$i_s(t) = i_{L1}(t) = I_1\cos\theta_1.\sin(\omega t+\theta_1) \quad (6)$$

where

$i_s(t)$ instantaneous supply current.

From Fig. 1, it can be found that the desired current filter supplied by the active power filter can be represented as:

$$i_F(t) = i_L(t) - i_s(t) \quad (7)$$

where

$i_F(t)$ instantaneous current filter

If the active power filter can supply the current filter $i_F(t)$, the supply current would be a sinewave and in phase with the supply voltage so that the power factor is near unity.

The power processing quality of a non linear load requires the determination of the Total Harmonic Distortion (THD) of the supply current. The THD must within certain admissible limits.

$$THD_i = \frac{\sqrt{\sum_{n=2}^{\infty}(Irmsn)^2}}{Irms1} = \frac{\sqrt{Irms^2 - Irms1^2}}{Irms1} = \sqrt{\frac{Irms^2}{Irms1^2} - 1}$$

where

THD_i Total Harmonic Distortion of the current;

Irmsn rms current of the nth order harmonic;

Irms1 rms current of the fundamental component.

The proposed active power filter: The control block diagram of the three phase shunt active power filter is represented in Fig. 2. In the proposed APF, three parameters has to be detected, the dc bus voltage, the three phase supply voltage and the three phase supply current. The signals of the three phase supply voltage are used to create three sinusoidal reference waves shifted by 120°, with unity magnitude. The dc bus voltage is used to give the information of the power balance; the power supplied from the supply must be equal to the real power demanded by the load.

The detected dc bus voltage is compared with a setting voltage. The difference between the signals is fed to a PI controller to create the desired magnitude of the supply current. The output of the PI controller and the sinusoidal reference per phase are fed to an analogue multiplier to create desired supply current $i_{sref}(t)$. The difference between the reference supply current and the detected supply current is fed to an error amplifier. The output of the error amplifier is the modulation signal. A carrier wave is compared with the modulation signal corresponding to a phase to generate the gating signals for that phase.

SIMULATION RESULTS

The simulation of the three phase shunt active power filter is carried out using Simulink Matlab program with two types of non linear loads.

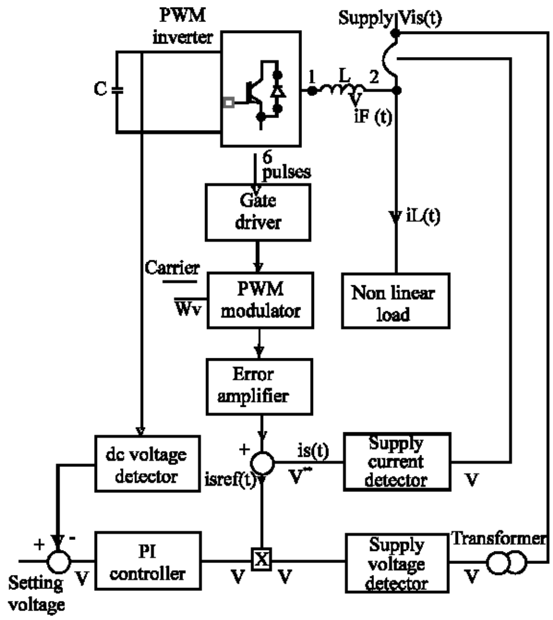

Fig. 2: Control block diagram of the proposed APF

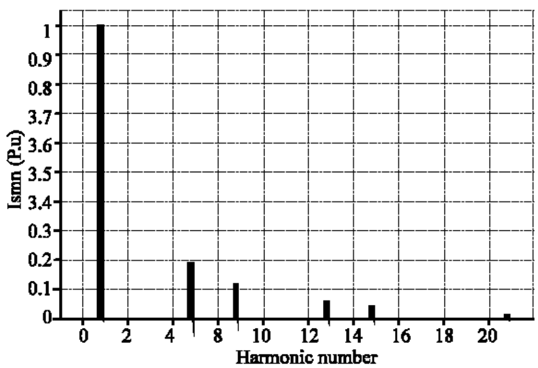

Fig. 3: Current waveforms of the load current $i_L(t)$, current filter $i_F(t)$ and supply current $i_s(t)$ and dc bus voltage with RL load

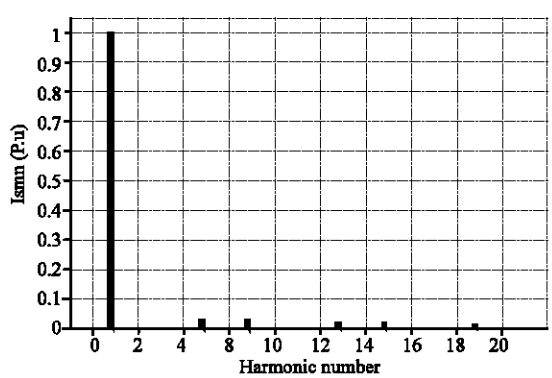

Fig. 4: Spectrum of the supply current before filtering with RL load

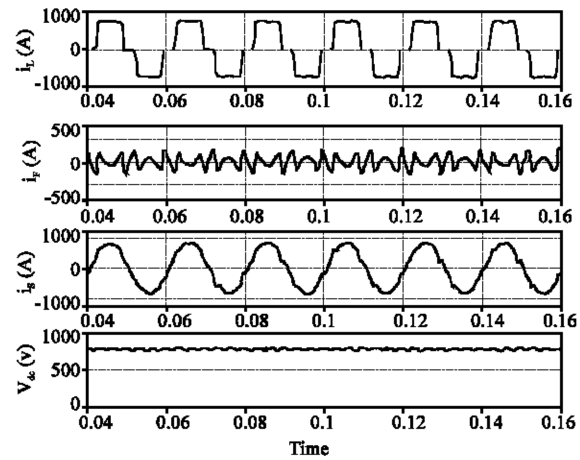

Fig. 5: Spectrum of the supply current after filtering with RL load

- First non linear load: diodes rectifier feeding an RL series load.

Figure 3 shows the waveforms of the load current, filter current, supply current of phase A and the dc bus voltage.

The effectiveness of the proposed method is demonstrated in the quality of the supply current after filtering as shown in Fig. 3. The supply current is a sinewave and in phase with the supply voltage.

The spectrum of the supply current of phase A before and after filtering is shown in Fig. 4 and 5, obtained by using Fast Fourier Transform algorithm (FFT). The peak supply current harmonics Ismn in per unit system (p.u.) after filtering have been reduced as shown in Fig. 5. The supply current THD before filtering is equal to 23.53% and have been reduced to 4.16% after filtering and meets the IEEE 519 allowable THD limit[8].

where

Ismn (pu) peak supply current of the nth order harmonic in per unit system (pu).

- Second non linear load: diodes rectifier feeding an RC parallel load.

To verify the good performance of the proposed APF with a change of linear load, the simulation has been carried out with a second non linear load. The waveforms of the load current, filter current and supply current are shown in Fig. 6. It can be seen from Fig. 6 that the supply current after filtering is always a sinewave and in phase with the supply voltage.

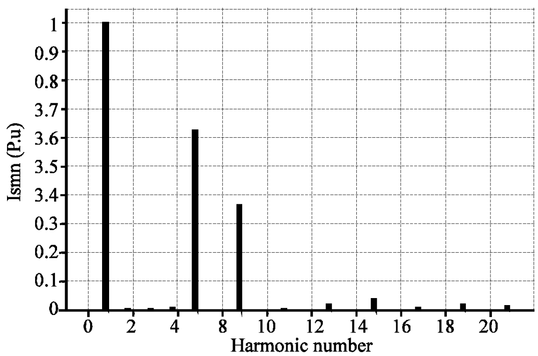

Fig. 6: Current waveforms of the load current $i_L(t)$, current filter $i_F(t)$, supply current i (t) and dc bus voltage with RC load

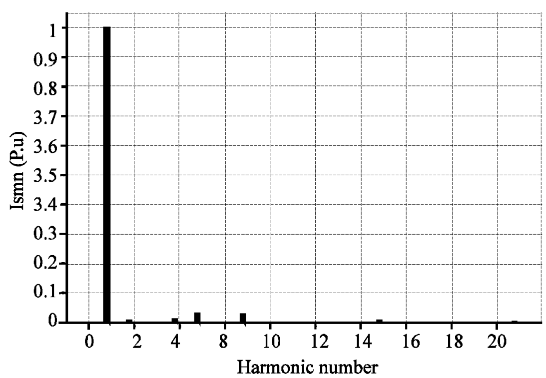

Fig. 7: Spectrum of the supply current before filtering with RC load

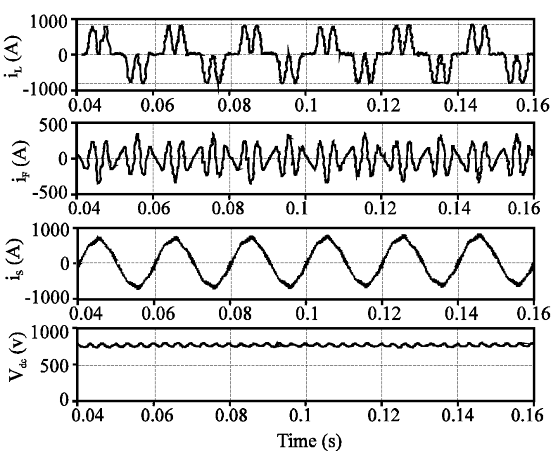

Fig. 8: Spectrum of the supply current after filtering with RC load

The spectrum of the supply current of phase A before and after filtering is shown in Fig. 7 and 8. The peak supply current harmonics Ismn after filtering have been reduced as shown in Fig. 8. The supply current THD before filtering is equal to 72.37% and have been reduced to 4.97% after filtering and meets the IEEE 519 admissible THD limit.

CONCLUSION

A three phase shunt active power filter for current harmonics suppression and reactive power compensation using the supply current as reference has been proposed. The proposed APF has a simple control circuit and low cost of implementation. From the above analysis and simulation results, it can be found that the proposed APF has all the performance of conventional active power filters. The effectiveness of the proposed method is demonstrated in the quality of the supply current after filtering and the reduction of the THD of the supply current. Therefore, the proposed APF can suppress the current harmonic to force the supply current to be a sinewave and compensate the reactive power.

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