

# A New Control Method for Single-Phase Active Power Line Conditioners

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**Abstract**—A new control method for single-phase shunt active power line conditioners (APLC's) operated under zero average power consumption is proposed in this paper. The amplitude of the sinusoidal source current which is in-phase with the source voltage can be determined from the average value of the instantaneous load power. Then the command current for the shunt APLC is obtained by subtracting the source current from the load current. Neither bulky filter nor time-consuming computation is required. The shunt power compensator supplies all the harmonics of the load current and the source only supplies the fundamental component. Experimental results on a prototype verify the feasibility of the presented scheme.

## I. INTRODUCTION

To reshape the distorted input currents caused by the increasing nonlinear and switching-mode loads, many researches have been focused on the power factor correctors recently[1]. The power capacities handled by these circuits are limited since they are connected in series between the sources and the loads. On the other hand, active power line conditioners (APLC's) inject harmonic currents into the system as shunt reactive power sources[2-4]. The block diagram of a power system with a shunt APLC is shown in Fig. 1. The voltage source PWM inverters are usually adopted as the power circuits of the shunt APLC's. Ideally, the shunt APLC neither contributes nor consumes any real power. Thus all the load power is supplied by the source. To achieve a unity input power factor,  $i_s(t)$  is controlled to be purely sinusoidal and in-phase with the source voltage. That is to say,  $i_h(t)$  should contain at least all the harmonics of the load current  $i_L(t)$ .

There are two time-domain compensation methods described in the literature for the shunt APLC to supply only the reactive part of the load power. The first method utilizes a 60 Hz filter to extract the fundamental component of the distorted input current[2]. The cost of the filter elements is

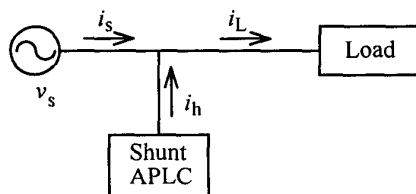


Fig. 1 Block diagram of a power system with a shunt APLC.

considerable if higher order and lower cutoff frequency of the filter are required. The second approach calculates the instantaneous reactive power, where the computation circuitry is somewhat complicated[3]. In this paper, a novel control strategy for the shunt APLC with zero average power consumption is proposed. The amplitude of the source current is determined from the average value of the instantaneous output power. The command current for the shunt APLC is then obtained by subtracting the source current from the load current. In the following paragraphs, the operation principles of the proposed control method will be discussed. Some experimental results of a prototype system are shown to verify the presented scheme.

## II. ZERO POWER CONSUMPTION OF THE SHUNT APLC

Fig. 2 illustrates the detailed diagram of a single-phase power system with a shunt APLC. The load is powered through a full-bridge diode rectifier. It is known that  $i_L(t)$  contains fundamental component  $i_{L1}(t)$  and harmonics of other orders. Without compensation, the power factor of the source will be poor even adding an input inductor. To achieve a unity power factor at the source side,  $i_s(t)$  must be purely sinusoidal and in-phase with  $v_s(t)$ . And to operate the shunt APLC with zero average power consumption, the average power supplied by the source,  $P_i$ , must be equal to the average power consumed by the load,  $P_o$ . Considering that the system is in its steady state, the conservation of power leads to

$$P_i = \frac{1}{2} V_s I_s = \frac{1}{2} V_s I_{L1} \cos\phi = P_o, \quad (1)$$

where  $V_s$ ,  $I_s$  and  $I_{L1}$  are the peak amplitudes of  $v_s(t)$ ,  $i_s(t)$  and  $i_{L1}(t)$ , respectively, and  $\phi$  is the phase difference between  $v_s(t)$  and  $i_{L1}(t)$ . From (1), it can be seen that  $I_s$  is proportional to the load power  $P_o$ . According to the KCL,

$$i_h(t) = i_L(t) - i_s(t), \quad (2)$$

$i_h(t)$  contains all the harmonics of  $i_L(t)$  and a fundamental component,  $i_{h1}(t)$ , which is the difference between  $i_{L1}(t)$  and  $i_s(t)$ . Since the AC side of the APLC is the source voltage with fundamental frequency,  $i_{h1}(t)$  must be out-of-phase with  $v_s(t)$  in order that the shunt APLC does not manipulate the real power. The statement above can be proved from (1) and (2),

$$\begin{aligned} i_{h1}(t) &= i_{L1}(t) - i_s(t) \\ &= I_{L1} \sin(\omega t + \phi) - I_s \sin\omega t \\ &= I_{L1} \sin(\omega t + \phi) - I_{L1} \sin\omega t \cos\phi \\ &= I_{L1} \sin\phi \cos\omega t, \end{aligned} \quad (3)$$

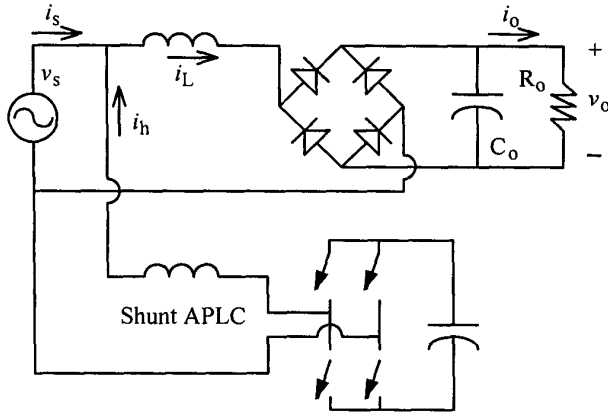


Fig. 2 The discussed single-phase power system.

where  $\omega$  is the fundamental frequency in radians per second. Normally, the dominant harmonics appeared in  $v_o(t)$  and  $i_o(t)$  are of 2nd-order. The instantaneous output power can then be expressed as:

$$\begin{aligned}
 p_o(t) &= v_o(t) \cdot i_o(t) \\
 &\cong V_o (1 + r_v \cdot \sin 2\omega t) I_o (1 + r_i \cdot \sin 2\omega t) \\
 &\cong V_o I_o (1 + r_v \cdot \sin 2\omega t + r_i \cdot \sin 2\omega t) \\
 &= P_o (1 + r_p \cdot \sin 2\omega t), \quad (4)
 \end{aligned}$$

where  $V_o$ ,  $I_o$  are the DC values of  $v_o(t)$  and  $i_o(t)$ , and  $r_v$ ,  $r_i$  and  $r_p$  are the ratios of the dominant 2nd-order harmonics to  $V_o$ ,  $I_o$  and  $P_o$ , respectively. It is concluded that the amplitude of  $i_s(t)$  is proportional to  $P_o$ , which is the average value or DC component of  $p_o(t)$ . Instead of filtering out the DC component, the peak and the valley of  $p_o(t)$  are detected by the peak detectors and averaged to obtain the value of  $P_o$ . The amplitude command of  $i_s(t)$  is then the product of  $P_o$  and a proper gain. The block diagram of the proposed control scheme is shown in Fig. 3. The shunt PWM converter supplies all the harmonics of the load current and a fundamental component which is out-of-phase. That is, the shunt APLC neither contributes nor consumes any average power.

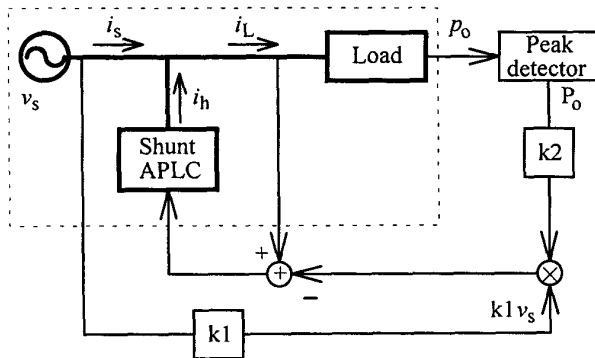


Fig. 3 The block diagram of the proposed peak output power detection control scheme.

### III. EXPERIMENTAL RESULTS

Some experimental results on a prototype system have been recorded. The system parameters are listed as follows.

$$V_s = 50\sqrt{2} \text{ V}, C_o = 470\mu\text{F}, R_o = 55\Omega, V_o = 50 \text{ V}$$

Fig. 4 shows the waveforms of  $v_s(t)$  and  $i_s(t)$ . It can be seen that the power factor is almost unity. The rms value of  $i_s(t)$  is 1A and the average input power  $P_i$  is 50W. The output power  $P_o$  is calculated to be about 45W. The power loss due to the nonideal circuit elements must be taken into account when designing the feedback gain. Here we assume that the overall efficiency of the system is 90%. Illustrated in Fig. 5 are the waveforms of  $i_s(t)$ ,  $i_h(t)$  and  $i_L(t)$ , where the conformity to the KCL can be observed. Under the proposed scheme, the source only supplies the in-phase fundamental current, while  $i_h(t)$  contains all the harmonics and the out-of-phase fundamental component. It can then be concluded that the shunt APLC consumes zero average power.

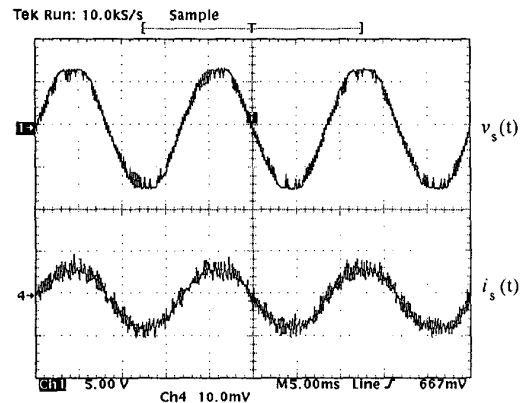


Fig. 4 The waveforms of  $v_s(t)$  and  $i_s(t)$ . Time: 5 ms/div; voltage: 50 V/div; current: 2 A/div.

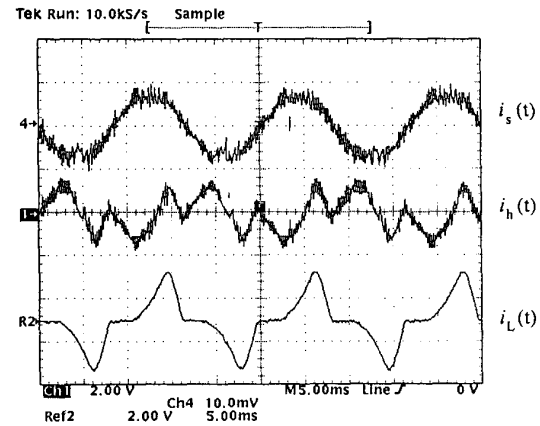


Fig. 5 The waveforms of  $i_s(t)$ ,  $i_h(t)$  and  $i_L(t)$ . Time: 5 ms/div; current: 2 A/div.

Fig. 6(a) shows the waveform of  $i_L(t)$  and its spectrum, where odd-order harmonics appear besides a fundamental. Fig. 6(b) shows the waveform of  $i_s(t)$  and its spectrum. It can be seen that the fundamental component dominates and the source supplies all the average real power. The waveform of  $i_h(t)$  and its spectrum are depicted in Fig. 6(c).

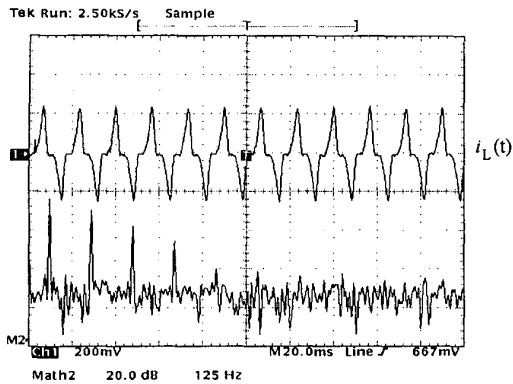


Fig. 6(a) The waveform of  $i_L(t)$  and its spectrum. Time: 20 ms/div; frequency: 125 Hz/div.; current: 2 A/div.

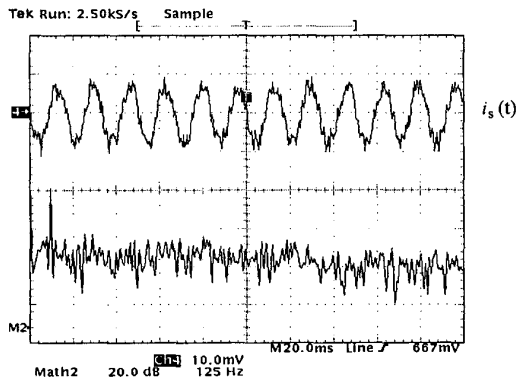


Fig. 6(b) The waveform of  $i_s(t)$  and its spectrum. Time: 20 ms/div; frequency: 125 Hz/div.; current: 2 A/div.

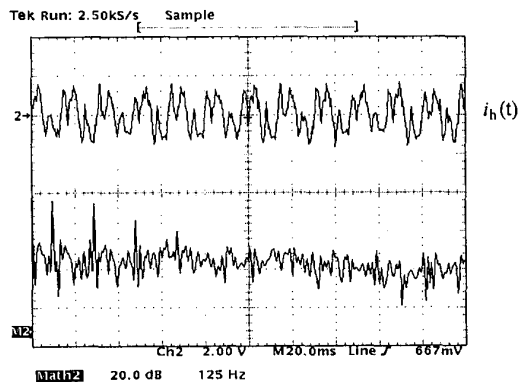


Fig. 6(c) The waveform of  $i_h(t)$  and its spectrum. Time: 20 ms/div; frequency: 125 Hz/div.; current: 2 A/div.

The shunt APLC injects all the harmonics of  $i_L(t)$  into the system. The fundamental component of  $i_h(t)$ , however, does not contribute any real power as discussed in Section II. The response of the presented system subject to load variation is recorded in Fig. 7. The load resistor  $R_o$  is changed from  $55\Omega$  to  $22\Omega$ . It can be clearly seen that the load power  $P_o$  is changed from 45W to 105W, and the rms value of  $i_s(t)$  is changed from 1A to 2.4A. The overall efficiency of the system remains around 90%. The response time is less than one period as observed.

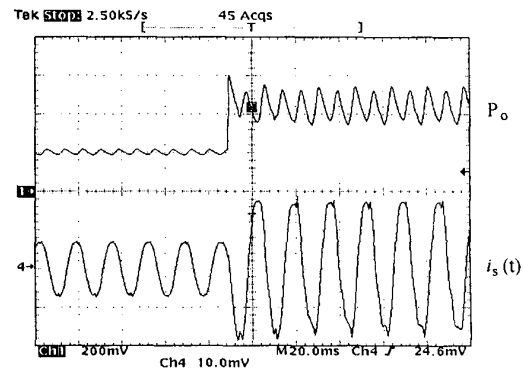


Fig. 7 The responses of output power  $P_o$  and the source current  $i_s(t)$  under load change. Time: 20 ms/div.; power: 45 W/div.; current: 2 A/div.

#### IV. CONCLUSIONS

In this paper, a novel control scheme for a shunt APLC operated under zero average power is presented. By sensing the DC value of the output power through the peak detection, the amplitude of the source current required by the source to supply all the average power can then be determined. The shunt APLC injects all the reactive power. Thus a unity input power factor can be achieved. Experiments on a prototype system show satisfactory results. The proposed scheme can be applied to three-phase system as well.

#### REFERENCES

- [1] J. C. Salmon, "Circuit topologies for single-phase voltage-doubler boost rectifier," *IEEE Trans. Power Elec.* vol. 8, no. 4, 1993, pp. 521-529.
- [2] H. Kawahira, T. Nakamura, and S. Nakazawa, "Active power filters," in *Proc. JIEE IPEC-Tokyo*, 1983, pp. 981.
- [3] H. Akagi and Y. Kanazawa, and A. Nabae, "Instantaneous reactive power compensators comprising switching devices without energy storage components," *IEEE Trans. Ind. Appl.* vol. 20, p. 625, 1984.
- [4] H. Akagi, "Trends in active power line conditioners," *IEEE Trans. Power Elec.* vol. 9, no. 3, p. 263, 1994.