Modulated Carrier Control for Single-Phase Active Power Filter

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ABSTRACT

In this paper, an improved modulated carrier control for a single phase shunt active power filter(SAPF), which eliminates harmonic currents at the ac main drawn by nonlinear loads, is introduced. In contrast to conventional methods, since this control method does not need to generate a current reference for SAPF, only the ac main current is sensed instead of the load current and SAPF current. With the proposed control method, the ac main current is directly controlled to be sinusoidal and in phase with the supplied ac voltage by simply comparing the modulated carrier signal with the ac main current. The operation of the proposed SAPF is analyzed and simulation results verify its performance.

1. Introduction

Nonlinear loads such as diode rectifiers with a capacitive or inductive load generate harmonic and reactive currents from ac sources and cause low efficiency, low power factor, and high total harmonic distortion (THD). Active power filter (APF) has attracted attention as a reasonable solution to get rid of aforementioned problems. Shunt active power filter (SAPF) is considered as the most basic and practical configuration[1]. In previously proposed control methods, the SAPF current and load current sensing is indispensable to detect harmonic currents which become the reference current of SAPF. However, this control method augments calculation burdens on DSPs and circuit complexity[2].

The proposed control method in this paper shapes the ac main current in the way the current follows the supplied ac voltage without creating the reference current for SAPF by directly comparing the ac main current with the modulated carrier signal. The method greatly simplifies the control circuit by eliminating SAPF input current and load current sensors. The simulation results validate that a single phase SAPF based on the proposed control method removes the undesirable currents.

2. Proposed Shunt Active Power Filter

2.1 Operation of SAPF power stage

Fig. 1 shows the topology of the SAPF which is a full bridge boost converter. The operation of SAPF is described as follows.

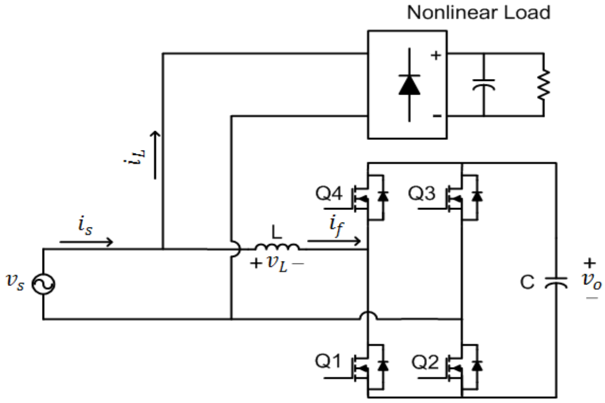

Fig. 1. A circuit diagram of single phase SAPF.

$$i)\ 0 \le t \le dT_s : Q1, Q3\ on\ (Q2, Q4\ off) \quad \text{(1.a)}$$
$$\Rightarrow v_L = v_s + v_o$$
$$ii)\ dT_s \le t \le T_s : Q2, Q4\ on\ (Q1, Q3\ off) \quad \text{(1.b)}$$
$$\Rightarrow v_L = v_s - v_o$$

On the assumption that the switching frequency of the SAPF is much higher than those of line and nonlinear load currents, and v_o is regulated to be a constant value V_o, the SAPF current i_f is constant during a switching cycle. Then, by using volt. sec. balance of the inductor L, the relation between the line voltage v_S and SAPF's dc voltage V_o is given by

$$V_o = \frac{1}{(1-2d)} v_s. \quad (2)$$

2.2 Proposed Control Scheme

To make the ac main current follow the line voltage, (3) must be satisfied that is a key concept of power factor correction control.

$$\frac{v_s}{\overline{i_s}} = R_e,\ v_s = R_e \overline{i_s} \quad (3)$$

By combining of (2) and (3), the control equation for the proposed control method is presented as

$$R_s \overline{i_s} = R_s \frac{v_o}{R_e}(1-2d) = v_m (1-2d), \quad (4)$$

where R_s is the line current sensing gain, $\overline{i_s}$ is the averaged ac main current in one switching period, and v_m is $v_o R_s / Re$, respectively. Then, Eq. (3) is realized by controlling d to satisfy (4) in each switching cycle. Fig. 2 illustrates the overall control strategy. In Fig. 2(a), the nonlinear load current i_L is represented as a current source. The sensed ac main current $R_s i_s$ is compared with a sawtooth waveform expressed as in (5).

$$v_c(t) = v_m(1 - \frac{4t}{T_s}) \quad (0 \le t \le T_s) \qquad (5)$$

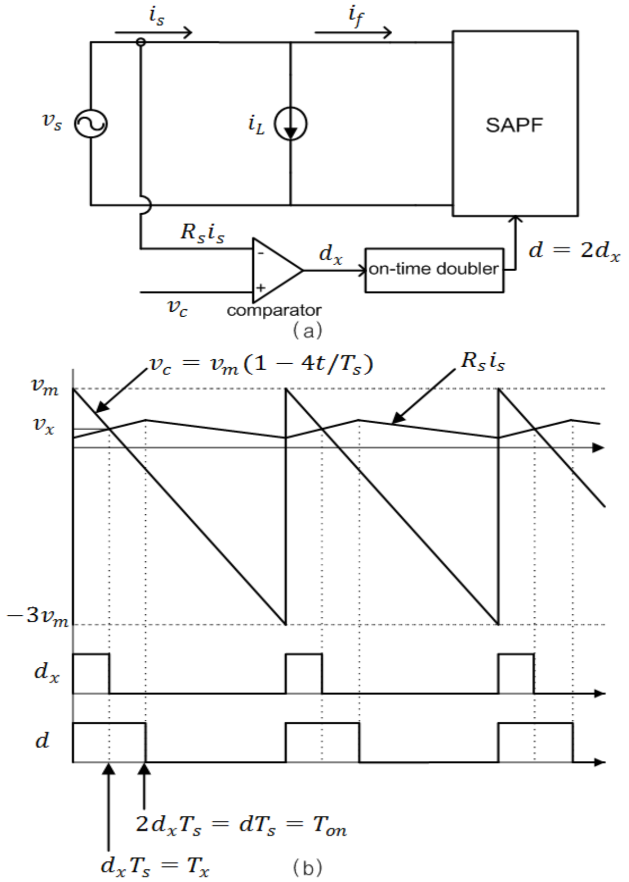

Fig. 2. (a) The proposed control block diagram
(b) Operation waveforms of the proposed control method.

When $R_s i_s$ reaches v_c, the comparator outputs d_x and this signal is processed to be doubled, $2d_x$, by the on time doubler in Fig. 2(a). Finally, the processed signal d becomes the duty ratio of the SAPF[3]. Modifying the duty ratio d as the two fold of d_x allows v_c to be compared with the average value of the sensed line current $R_s \overline{i_s}$ which, in turn, guarantees no appearance of dc offset problem mentioned in [2]. From the explanation of the operation above and Fig. 2(b), the following equation is obtained.

$$v_x = R_s \overline{i_s} = v_c(T_x) = v_m(1 - 4T_x/T_s) = v_m(1-2d) \qquad (6)$$

Combination of (2) and (6) yields

$$R_s \overline{i_s} = v_m(1-2d) = v_m \frac{v_s}{V_o}, \qquad (7)$$

$$\frac{v_s}{\overline{i_s}} = R_s \frac{V_o}{v_m} = R_e. \qquad (8)$$

It is inferred from (8) that the average ac main current is proportional to v_s and this allows a unity power factor with the ac voltage. Therefore, parallel connection of the nonlinear load and SAPF emulates a resistive load from the viewpoint of the ac system.

3. Simulation Results

The proposed single phase SAPF based on the modulated carrier signal control is simulated. Fig. 3 shows that

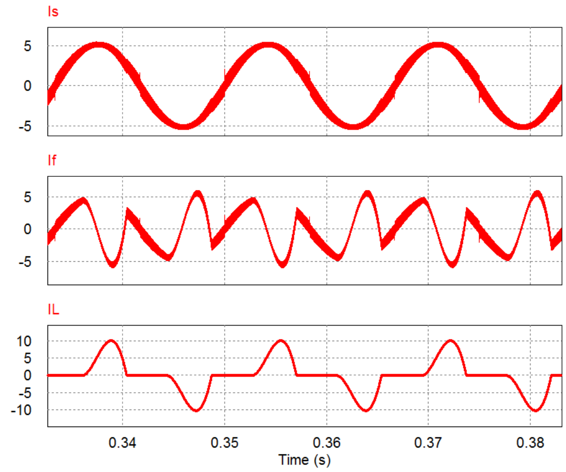

Fig. 3. The simulation results of the proposed SAPF : line current(i_s), SAPF current(i_f), nonlinear load current(i_L).

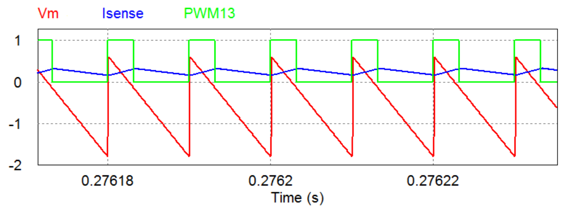

Fig. 4. The simulated waveforms of the controller operation.

regardless of how much current flows to the nonlinear load, the ac main current contains mostly the fundamental element. Consequently, the proposed SAPF compensates reactive and harmonic current properly. Fig. 4 represents the switching mechanism of the proposed modulated carrier control method.

4. Conclusion

To minimize calculation burden on DSPs and circuit complexity of conventional SAPF control methods, the literature introduces a direct ac main current control with an improved modulated carrier control. The simulation results have proved that it can eliminate harmonic current and reactive current generated by nonlinear loads and overcome the dc offset problem.

Reference

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[3] Hye Jin Kim, Bo Hyung Cho, "Modulated Carrier Control for Interleaved Continuous Conduction Mode Boost Power Factor Correction Converter", *in Proc. Power Electronics Annual Conference*, KIPE, pp.195 196, 2012.