

# An Advanced Current Control Strategy for Three-Phase Shunt Active Power Filters

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**ABSTRACT:** This paper proposes an advanced control strategy to enhance performance of shunt Active power filter (APF)(1). The proposed control scheme requires only two current sensors at the supply side and does not need a harmonic detector. In order to make the supply currents sinusoidal, an effective Harmonic compensation method(2) is developed with the aid of a conventional proportional-integral (PI)(3) and vector PI controllers. The absence of the harmonic detector(4) not only simplifies the control scheme but also significantly improves the accuracy of the APF. Despite the simplified hardware, the performance of the APF is improved significantly compared to the traditional control scheme, thanks to the effectiveness of the proposed compensation scheme. The proposed control scheme is theoretically analyzed, and a 1.5-kVA APF(5) is built in the laboratory to validate the feasibility of the proposed control strategy.

**KEYWORDS:** Active power filter, Harmonic compensation method, Proportional-integral(PI), Harmonic detector, 1.5-kVA APF.

## I. INTRODUCTION

The increasing use of nonlinear loads such as adjustable speed drives, electric arc welders, and switching power supplies causes large amounts of harmonic currents inject into distribution systems. These harmonic currents are responsible for voltage distortion, increasing power losses and heat on networks and transformers, and causing operational failure of electronic equipment.[1] In order to improve the power quality of distribution networks as well as to meet these restriction standards, two main solutions have been introduced: LC passive filters and active power filters (APFs). LC passive filters are traditionally utilized to compensate the harmonic currents since they are simple and low-cost solution. Furthermore, the compensation capability of a passive filter is typically fixed and relies heavily on a network's impedance, thus potentially causing undesired resonance problems.[2-4]

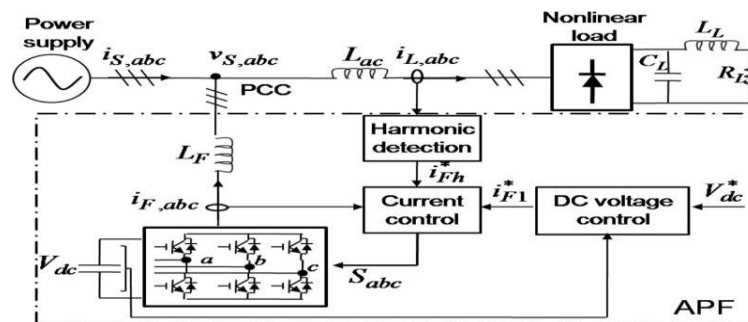


Figure1-Typical control scheme of a shunt APF



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In contrast, shunt APFs are recognized as a flexible solution for harmonic current compensation since they are capable of compensating harmonic currents generated by many types of nonlinear loads as well as providing fast responses to load variations. [5] A typical control scheme of a shunt APF is illustrated in Fig. 1. The purpose of an APF is to generate harmonic currents ( $iF,abc$ ) having the same magnitude and opposite phase with the harmonics produced by the nonlinear load, and to ensure that the supply currents ( $iS,abc$ ) contain only the fundamental component. In order to realize the desired goals, as shown in Fig. 1, the traditional control scheme requires several steps such as load current measurement, harmonic current detection, reference filter current generation, and filter current control. [6] Since the APF must generate non-sinusoidal currents, the design of the current controller for the APF is a challenging task. Various control methods have been developed in the literature such as proportional-integral (PI) control, dead-beat control, and hysteresis control. Due to the limitation of the control bandwidth, the PI controller is not a suitable solution for the APF applications since the current controller must deal with harmonic currents, which are high-frequency signals. In contrast, the dead-beat control method is able to provide fast control response, but the control performance relies significantly on knowledge of the APF parameters. Despite the simple and robust feature of the hysteresis controller, this approach also has an inherent drawback: switching frequency variation, which causes a difficulty in design of an output filter for the APF and results in unwanted resonance problems with the networks. In addition, in order to achieve good current performance, the hysteresis and must be set as small as possible. It results in a significant increasing of the switching frequency and consequently introduces higher switching loss on the APF. [7]

## II. PROPOSED CONTROL STRATEGY TO IMPROVE APF PERFORMANCE

### A. Structure of a Shunt APF

Three-phase diode rectifiers are widely used as the front-ends of industrial ac drives. These types of loads introduce harmonic currents into the networks, which have odd orders:  $6n \pm 1$  ( $n = 1, 2, 3 \dots$ ) of the fundamental frequency. Since these harmonic currents cause serious problems and deteriorate the power quality of the distribution networks, the shunt APF was developed to compensate those harmonic currents and consequently to improve the power quality. As illustrated in Fig. 1, a shunt APF is basically a three phase voltage source inverter (VSI) connected in parallel with a nonlinear load at the point of common coupling through an inductor  $LF$ . The energy storage of the APF is a large capacitor located at the dc-link side of the inverter. The nonlinear load can be presented as a RL or RLC load connected to the power supply through a three-phase diode rectifier as shown in Fig. 1. As stated earlier, the APF must generate the harmonic currents to compensate harmonics produced by the nonlinear load and to make the supply currents sinusoidal. To fulfill these demands, the traditional control scheme requires a harmonic detector and current controller where both loops must be designed properly to achieve good control performance. [8] However, it may cause excessive complexity in the design process.

### B. Proposed Control Strategy

In order to simplify the control scheme and to enhance the accuracy of the APF, an advanced control strategy is proposed, as shown in Fig. 2. In Fig. 2, the proposed control scheme is implemented by using only the supply current ( $iSa$  and  $iSb$ ) without detecting the load current ( $iL,abc$ ) and filter current ( $iF,abc$ ). Thereby, the load current sensors and filter current sensors in the typical shunt APF shown in Fig. 1 can be eliminated. And also, the harmonic current detection is omitted. [9-11] Due to the absence of harmonic detection, the proposed control scheme can be implemented with only two loops: the outer voltage control and the inner current control. The outer loop aims to keep dc-link voltage of the APF constant through a PI controller, which helps the APF deal with load variations. The output of this control loop is the reference active current in the fundamental reference frame ( $i^* Sd$ ). Meanwhile, the reference reactive current ( $i^* Sq$ ) is simply set to be zero, which ensures the reactive power provided by the power supply to be zero. And, the reactive power caused by loads is supplied by the shunt APF. The inner loop is then used to regulate the supply current in the fundamental reference frame ( $iS,dq$ ) by using the proposed PI-VPI current controller. The output of this loop becomes the control signal ( $v^* F,ab$ ) applied to the four-switch APF which is implemented by the FSTPI. Since the current control is executed without the harmonic detector, the control performance of the APF only relies on the current controller. In the next section, the analysis and design of the proposed current controller will be presented. [12]

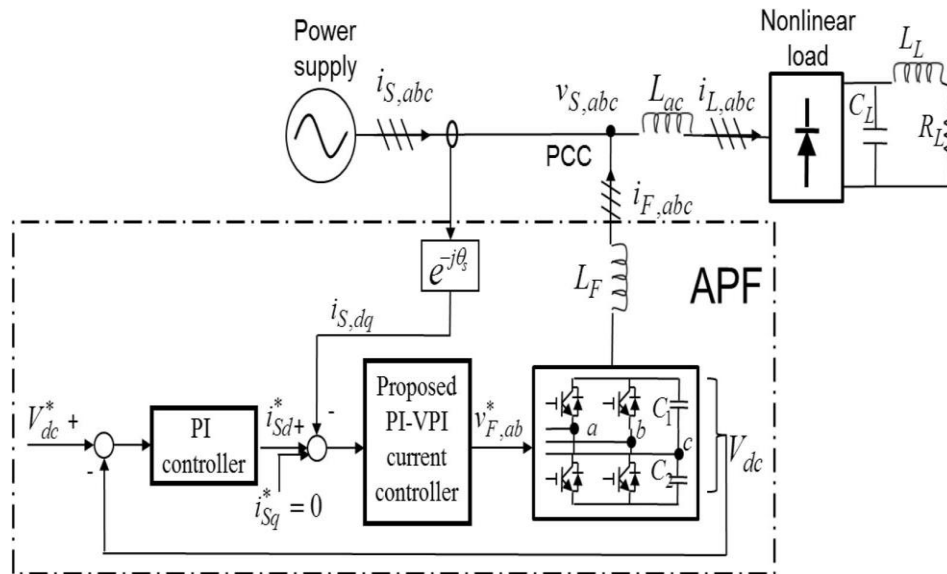


Fig. 2. Structure of the proposed control scheme for three-phase shunt APF.

### III. DESCRIPTION OF THE WHOLE CONTROL STRATEGY

Fig. 3 illustrates the block diagram of whole proposed control strategy. As aforementioned, the proposed control scheme contains two main loops: the dc-link voltage control and the supply current control. In addition, since the proposed current controller is employed in the fundamental reference frame, a phase-locked loop (PLL) is required to track the phase of the supply voltage which is needed for coordinate transformation and synchronization.[13]

#### A. DC-Link Voltage Control Loop

This control loop aims to keep dc-link voltage of the shunt APF constant through a simple PI regulator, whose output is the reference active current in the fundamental reference. In the proposed control scheme, the role of the dc-link voltage controller is not only to ensure a proper operation of the APF but also to help the APF deal with load variations. In this paper, even though the load current measurement is not used, the load changes can be detected indirectly through dc link voltage variations.[14]

#### B. Supply Current Control Loop

This loop regulates the supply current by means of the proposed current control scheme. The reference active current  $i^*_{Sd}$  is the output of the dc-link voltage control loop given in while the reference reactive current  $i^*_{Sq}$  is simply set to be zero. Consequently, the reactive power caused by loads can be fully compensated by the APF, and also unity power factor condition is achieved at the supply side.

#### C. Supply Voltage PLL

The aim of this loop is to track the phase of the supply voltage, which is a necessary component for any converter interfacing with grid. In practical distribution network, supply voltage is regularly not pure sinusoidal but contains harmonic components, which may affect to the accuracy of the PLL. To overcome this problem, a bandpass filter (BPF) tuned at the fundamental frequency of the supply voltage is implemented to reject all of the harmonic components contained in supply voltage and its output contains only the fundamental component which is used as the input of the PLL block. The block diagram of the improved PLL is illustrated in Fig. 10. Even though the BPF used in the PLL can cause a small time delay in tracking the phase angle of the supply voltage, it is negligible because the PLL usually operates at steady-state condition before the APF is active.

## IV. EXPERIMENTAL RESULTS

The system consists of a 1.5-kVA shunt APF and a 3-kVA nonlinear load with the parameters. The control algorithm was implemented using a 32-bit fixed point DSP (TMS320F2812 by Texas Instruments), with a 150-MHz clock frequency. The control sampling and switching frequencies are set at 10 kHz. The current controller is designed with one PI controller and five VPI controllers, capable of compensating all of the harmonic currents up to the 31st harmonic (1860 Hz). The gains of the controllers were individually tuned. The supply voltage is generated by a 6-kVA Programmable AC Power Source (Chroma 61704) that is able to produce either ideal sinusoidal or distorted supply voltage sources to investigate the performance of the proposed control strategy. Two types of nonlinear loads were used in the experimental tests, i.e., the RL and RLC loads connected to the power supply through a diode rectifier[15-19].

To demonstrate the superiority of the proposed control algorithm as compared to the traditional PI control scheme, an experimental test under the same condition was carried out by using the proposed control scheme. That the harmonic currents are effectively compensated and the supply current is almost sinusoidal with a small THD factor of approximately 1.65% whereas the load current is highly distorted with the THD factor of 25.2%. From these results, the effectiveness of the proposed control scheme is verified: harmonic currents are effectively compensated without load current measurement and harmonic detector. In addition, the proposed control scheme avoids the presence of notches in the supply current caused by the inaccurate harmonic tracking performance of the harmonic detector as reported

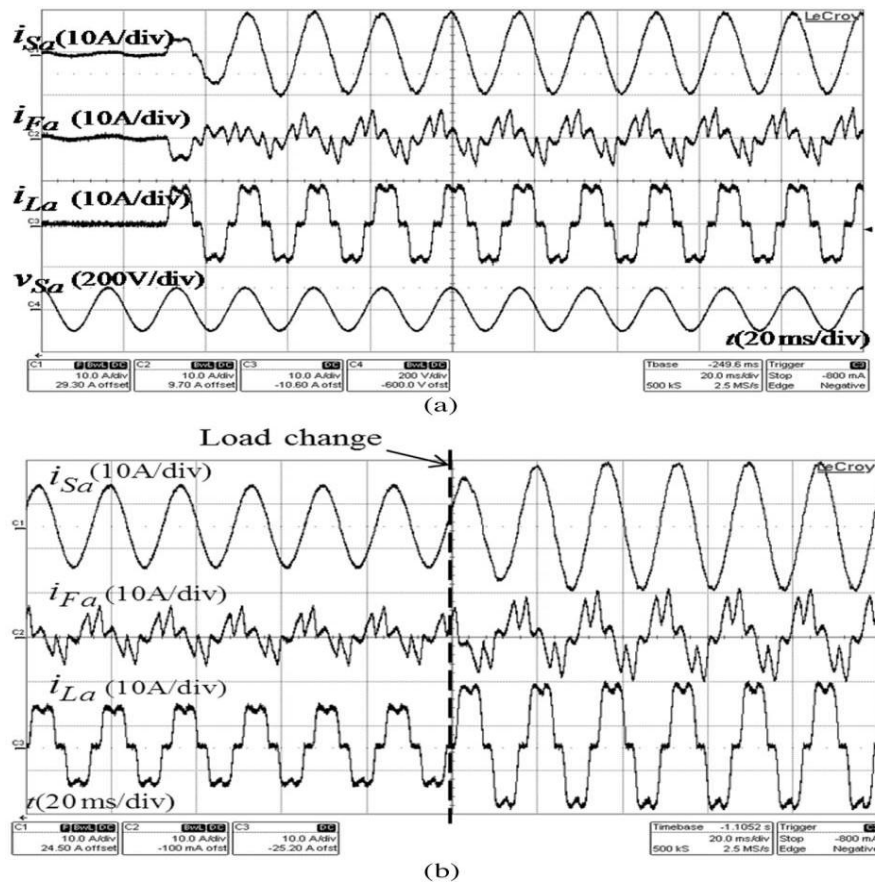


Fig. 3. Dynamic responses of proposed control scheme under RL load variations: (a) load applied (b) load changed.



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## V. CONCLUSION

In this paper, an advanced control strategy for the three-phase shunt APF was proposed. The effectiveness of the proposed control strategy was verified through various experimental tests, where the proposed control strategy presented good steady-state performance with nonlinear RL and RLC loads as well as good dynamic response against load variations: the supply current is almost perfect sinusoidal and in-phase with the supply voltage even under the distorted voltage condition. The experimental results verified that the absence of a harmonic detector results in faster transient responses as well as assures notches free in steady-state performances of the supply current. Moreover, we also confirmed that the FSTPI can be used to implement the APF without any degradation in the APF performance. In all of the experiments, THD factor of the supply current was reduced to less than 2%, which completely comply with the IEEE-519 and IEC-61000-3-2 standards.

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