The Source Current Detection Technique Used to Implement the Shunt Active Power Filter

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ABSTRACT

This paper presents the source current detection technique used to implement the shunt active power filter. The Shunt active power filter has been proved to be an effective method to mitigate harmonic currents generated by nonlinear loads as well as to compensate reactive power. The harmonic current and reactive power compensation of shunt active power filter controller is based on the digital signal processing (DSP) to control its operation. First, the signal quality of the designed prototype was tested with the simulation program. Then, the prototype for experiment has been setup for verifying the performance of system. It was found that reactive power could be compensated and harmonic current could be reduced, compared to the results of an active power filter with the load current detection. Since the source current detection used less controlling devices and its structure was simple, so it is more attractive.

Keywords – **Shunt active power filter, Source current detection , Load current detection.**

I. INTRODUCTION

In a modern power system, due to broader applications of nonlinear loads such as Power electronic devices have been developed continuously and rapidly. Electric appliances such as adjustable speed drives, arc furnaces, uninterrupted power supply, and single-phase computer power supply are widely used both in residential and industrial work. However, these appliances consist of non-linear loads with the resulting harmonic current that produces the distortion of voltage and current. As a result, a passive LC filter is developed to eliminate these harmonic currents. However, this method is suitable only for using with constant harmonic current. Recently, an active power filter has been developed to eliminate all levels of harmonic current as well as to compensate reactive power, using the shunt active power filter to supply the compensate current as in [1]-[6].

Principally, the active power filter operates by detecting harmonic current to calculate the amount of the compensate current needed for feeding back to the power system in the opposite direction of the harmonic current. The current detection is divided into two main types: load current detection [1] as illustrated in Fig. 1, and source current detection [2] as illustrated in Fig. 2. The active power filter with a detector of load current, voltage and compensate current are calculated the amount of harmonic current to control the quantity of compensate current needed accordingly.

This paper presents an implementation of shunt active power filter by using source voltage and source current detection. The performance of active power filter using source voltage and source current is implemented and tested. In addition, the test results are compared with those of the active power filter with current load detector within the same range of load. The prototype was designed and implementation by using the operating control of digital signal processing (DSP).

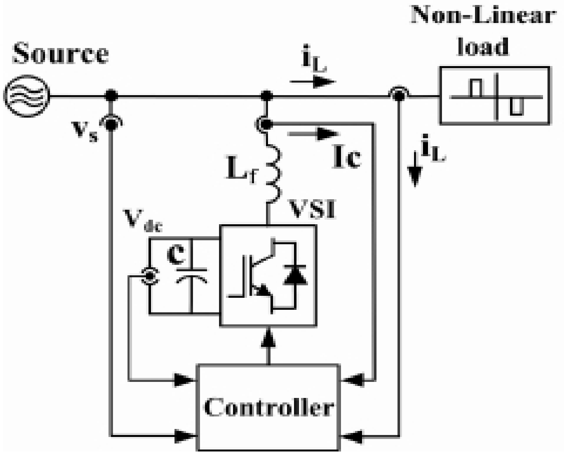


Fig. 1. Active power filter with load current detection.

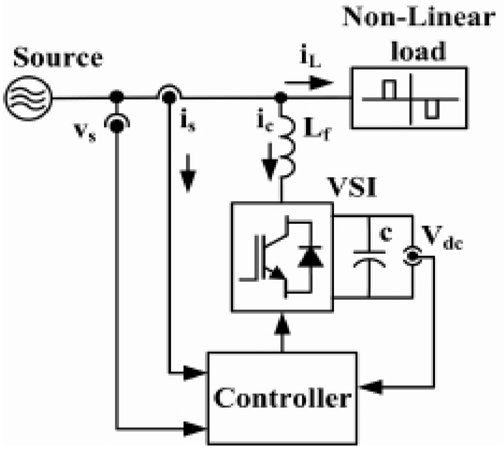


Fig. 2. Active power filter with source current detection.

This paper first discusses the principle of operation of active power filter, including the controller scheme of the active power filter. Then, the simulation results are presented. Next, the hardware implantation is presented. Then, typical waveforms are given to document the operation of active power filter in experimental results. Finally, the conclusion comments on this work are provided.

II. PRINCIPLE OF OPERATION

Typically, the active power filter compensates reactive power and reduces harmonic current occurring from non-linear load. Active power filter with source current detection only measures source current, source voltage and capacitor voltage. The basic compensation principle of a shunt APF is shown in Figure 3. It is controlled to draw/supply a compensating current Ic from/to the system, so that it cancels current harmonics on AC side, and makes the source current in phase with the source voltage. This is to make the source current as close as possible to the fundamental sinusoid, and the power factor close to unity [3]. Figure 3 illustrates the operating structure of the active power filter with a source voltage and current detector in the simulation and implementation.

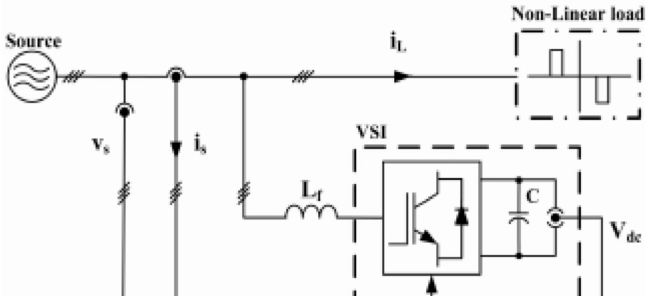


Fig. 3. Active power filter controller with a source voltage and current detector.

The active power filter with a source current detector in Fig. 3 can calculate the compensate current by detecting the source voltage (v_{sa} , v_{sb} , v_{sc}) and source current (i_{sa} , i_{sb} , i_{sc}). The desired source current is the fundamental sinusoidal and unity power factor as shown in (1).

$$i_{sa} = I_{a\max} \sin\omega t \qquad (1)$$

After that, the voltage and the dependent three-phase current connected on two reference axes (dq axes) are converted with Clarke's transformation. The voltage passes through a digital phase loop before the reference sinusoidal signal is produced and multiplied with the DC voltage and current, using a PI controller to obtain a gradual reaction. Therefore, the reference current in dq coordination can be derived as shown in (2).

$$i^*_{s1,dq} = \left(\left(V^*_{dc} - V_{dc}\right)\frac{\omega_f}{s+\omega_f}\right)\left(K_P + \frac{K_I}{s}\right)\left(I_{a\max}\sin\omega t\right) \qquad (2)$$

Then, the reference current (i^*_{S1}) is compared with the source current (i_{sd} , i_{sq}), using the P controller for quick reaction. The compensate current is calculated as shown in (3), then, it is used to generate PWM signal for control voltage source inverter.

$$i_{h,dq} = K_p\left(\frac{1}{sL_f+R_f}\right)\left(\left(K_P+\frac{K_I}{s}\right)\left(V^*_{dc}-V_{dc}\right)\frac{\omega_f}{s+\omega_f}\right) - I_s\, I_{a\max}\sin\omega t \qquad (3)$$

III SIMULATION RESULTS

The active power filter in Fig. 3 operates with the source voltage and current detection. Its operation was simulated by using MATLAB/ SIMULINK with SimPower Systems Model as the model of 2500 VA 380 V illustrated in Fig. 4 There is a non-linear load with three-phrase bridge rectifier connected to the resistor. The results of the simulation are illustrated in Fig. 5. The measuring unit is in phase A including voltage source (v_s), load current (i_L), Compensate current (i_c), source current (is). The waveform of source current is close to fundamental sinusoid, showing that harmonic current is eliminated from the source current. Therefore, it can be concluded that the proposed active power filter can compensate harmonic current. In comparison, the results of the active power filter with load voltage and current detector in the same range are illustrated in Fig. 6.

IV. HARDWARE IMPLEMENTATION

Since the harmonic elimination and the compensation of reactive power necessarily occurs in real time. This means that the selected components must be capable to work in high frequency. The prototype is implemented and verified through the experiments as the following components as shown in Fig. 7. The prototype of active power filter has been built as shown in Fig. 8. A selected power device is a discrete IGBT model IRG4PH50KD with rated voltage at 1,200 V and current at 24 A. Six of power devices are composed into a three-phase voltage source converter circuit. The analog signal is converted into the digital signal by using IMAX196ACNI 12 bit resolution, software-selection input range, 6 analog input, 6µs conversion time. The voltage and current sensor use HCPL-788J.

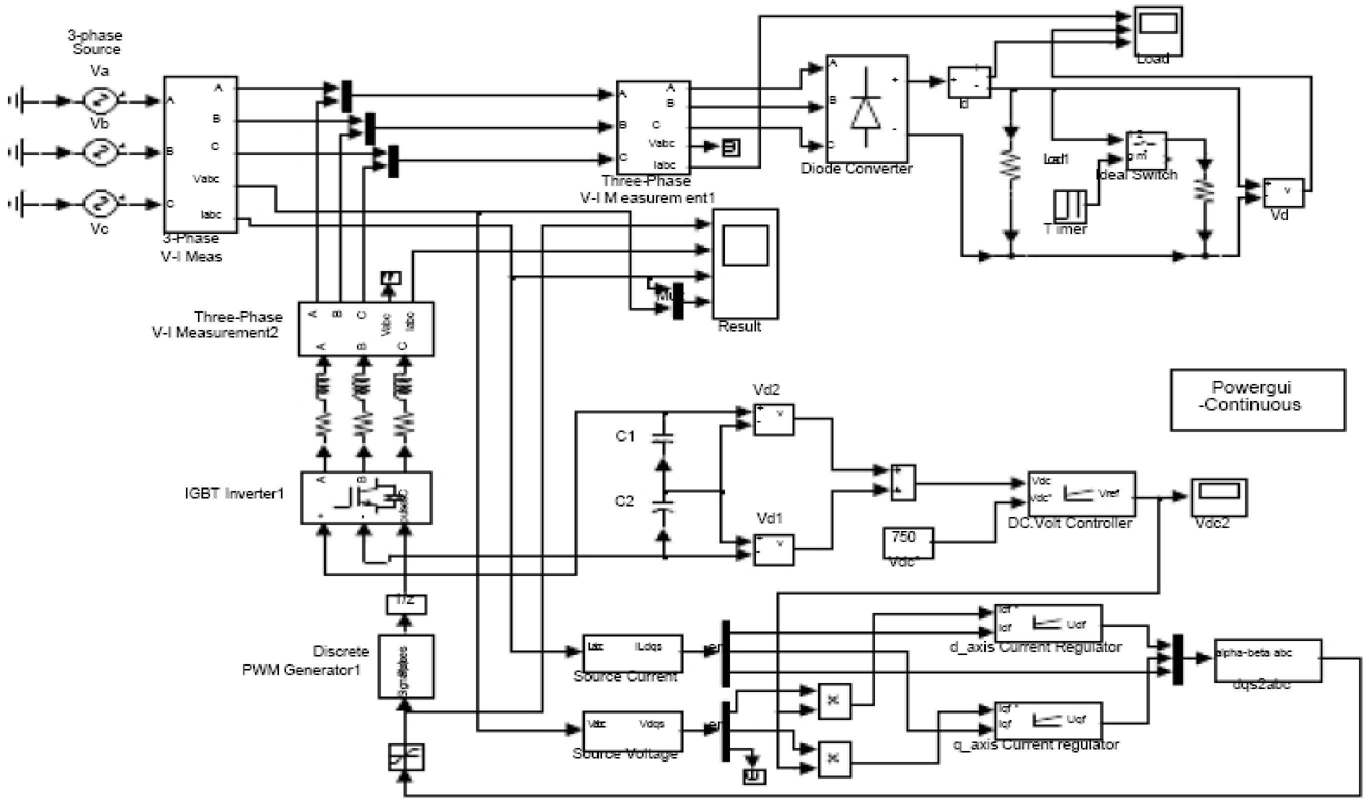


Fig.4. Simulation with SimPower Systems Model.

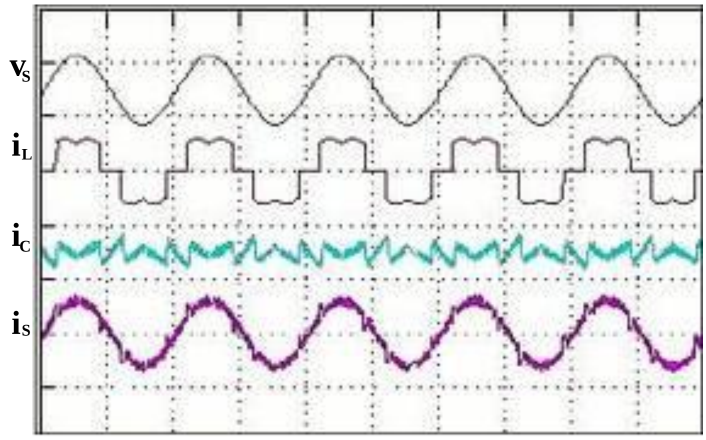


Fig. 5. The test results with the source current detection.

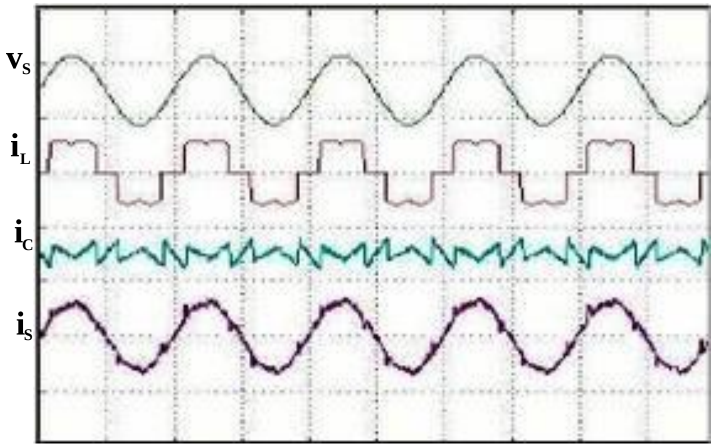


Fig. 6. The test results with the load current detection.

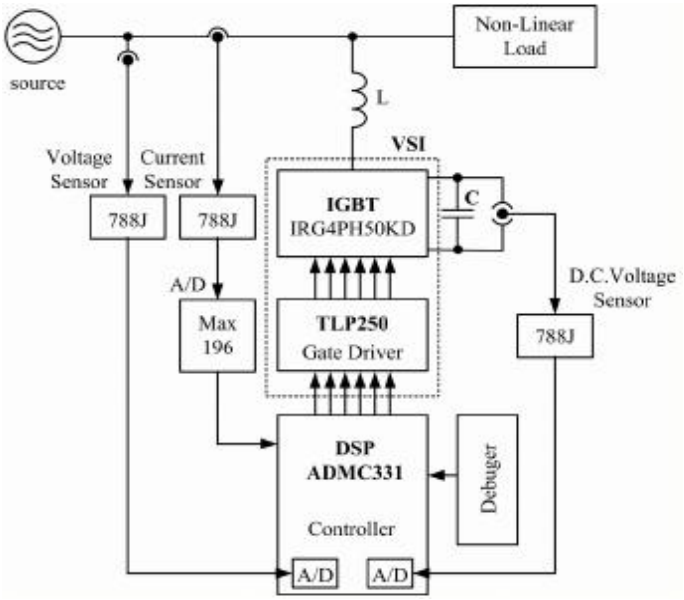


Fig. 7. Hardware implementation block diagram of active power filter.

Fig. 8. Hardware setup for active power filter.

The operation of the prototype is controlled with digital signal processor (DSP) ADMC331BST, a low cost single chip DSP microcontroller optimized for standing alone applications. The microcontroller integrates a 26 MHz fixed- point DSP core and a set of control peripherals including seven analog input channels and a 16-bit three-phase PWM generator. ADMC331 has two auxiliary 8-bit PWM channels and adds expansion capability through the serial ports and an 24-bit digital I/O port. ADMC331 also has internal 2Kx24-bit words program RAM, and I K x 16-bit words data RAM, which can be loaded from an external device via the serial port. ADMC331 can operate with a 38.5ns instruction cycle time. Every instruction can execute in a single processor cycle. The flexible architecture and comprehensive instruction set of ADMC331 allow the processor to perform multiple operations in parallel [5].

Regarding the software, the software flow chart is illustrated in Fig. 9. The operation of the program starts from determining various values of the programs, to obtain the values of voltage and A/D conversion. Regarding the current, the programs are designed to work together with IC Max 196 to obtain the values and A/D conversion as well as to connect through the I/O port of ADMC331. Then, the voltages and currents in dq coordination (i_d , i_q , v_d , v_q) are calculated using the Clark's transformation.

The voltage DC bus through the PI control and v_d , v_q are calculated for reference currents. These reference currents are compared with i_d , i_q, to obtain the value of compensate current through the P controller. After that, the results are used to create the PWM signals for controlling the operation of the driver.

V. EXPERIM ENTAL RESULTS

This section discusses the operation of the system shown in Fig. 7-8. The system was built and experimentally evaluated to learn more about the operation of the three phase active power filter. The rated of the prototype is 2500 VA 380 V was built with the system components are described in Table I.

TABLE I
PARAMETER OF EXPERIMENTAL SETUP.

Source voltage (V)	Load (W)	DC bus voltage (V)	DC bus capacitor (µF)	Filter inductor (L_f) (mH)	Switching frequency (kHz)
380	2,500	750	5000	10	10

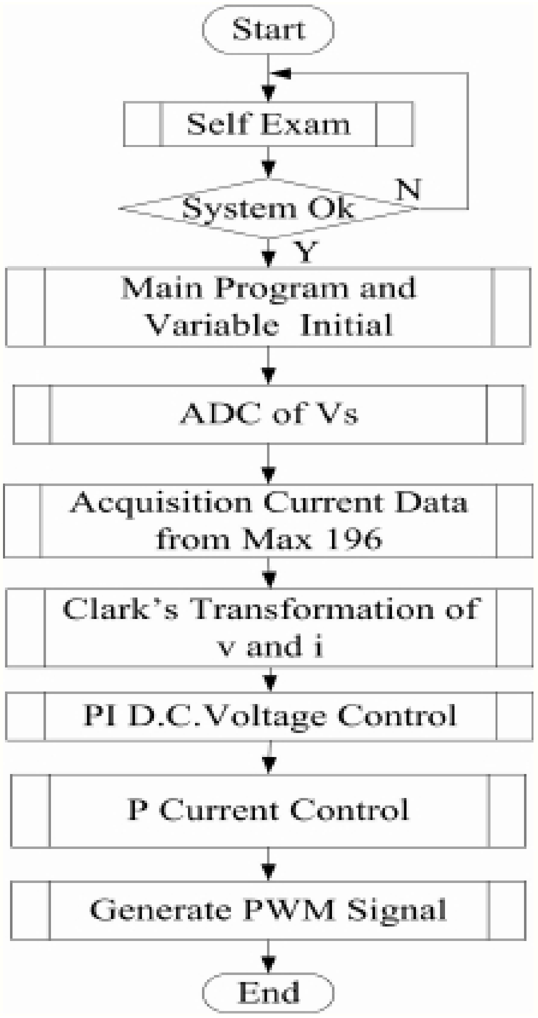


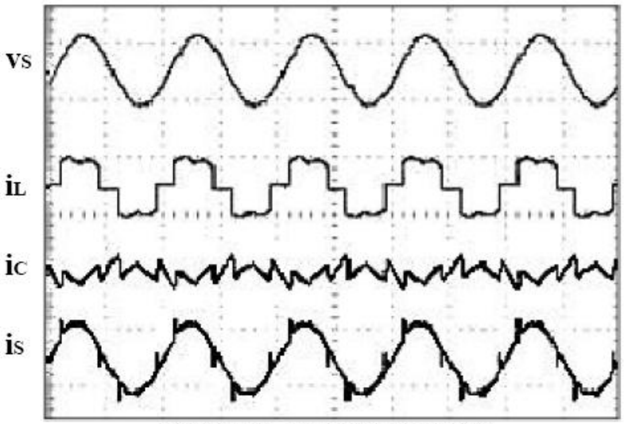
Fig. 9. Software flow chart of controller.

The operation of the prototype starts from the source voltage and current sensor ((i_{sa} , i_{sb} , i_{sc}),(v_{sa} , v_{sb} , v_{sc})) through IC 788J. The voltage is connected to input A/D of DSP where as the current is connected to input of Max196 to convert A/D and to bring the converted signal into input of DSP. After that, the compensate current is calculated with the developed program to generate control signal for controlling active power filter to supply the compensation into the system for deducing the harmonic current.

The test results of the prototype are shown in Fig. 10. The source current sensor displays the results in phase A with the measuring units of voltage source (v_s), load current (i_L) , compensated current (i_c) , and source current (i_s) . The performance of the active power filter is measured by the power factor and the total harmonic distortion (THD) of the resulting line currents. The power factor and THD are based on a pure sine wave for the voltage. That means the distortion voltages present in the source voltage have not been considered. Experimental results reveal that the resulting waveform is close to fundamental sinusoid. The power factor increases from 0.90 to 0.99. The value of THD decreases from 29.66% to 6.26% as shown in Table II. From the experimental results, the higher nonlinear load has higher power factor, thus the filter has to draw less current tocompensate load. As a result, the power loss decreases as the nonlinear load is increasing because the active power filter must provide less reactive power. As seen from the experimental results, the proposed active power filter can compensate the harmonic current, compared to the active power filter with load current detector in Fig.11. Since the source current detection used less controlling devices and its structure is simple, so it is more attractive.

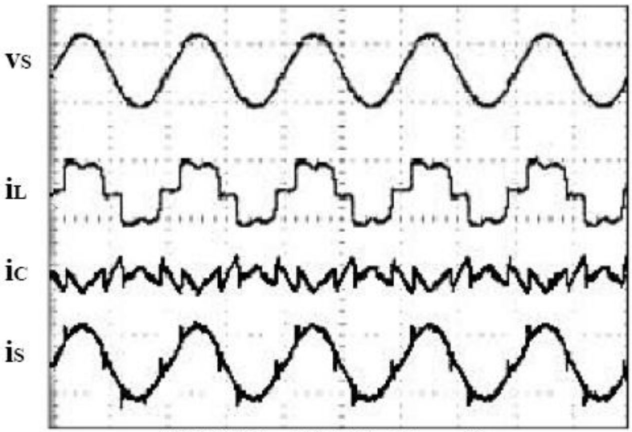
TABLE II
A summary of system performance as the load is varied

Measure	Nonlinear Load (W)							
	750		1,320		1,860		2,460	
	iload	*i s*	*iload*	*i s*	*iload*	*i s*	*iload*	*i s*
THD (%)	28.56	13.56	28.73	11.26	29.10	9.63	29.66	6.26
P_{loss} (W)	510		420		360		240	
| (%)	59.52		75.86		83.78		91.11	



1000V/div, 10 A/div 10 ms/div

Fig. 10. The test results with the source current detection.



1000V/div, 10 A/div 10 ms/div

Fig. 11. The test results with the load current detection.

VI. CONCLUSIONS

This paper has presented an implementation of shunt active power filter by using source voltage and source current detection. The compensation of harmonic current with source current detection can eliminate the harmonic current and can compensate reactive power. The performance of proposed control strategy has been investigated and verified through simulations and experimental results. The compensation responses quickly with simple methods compared to the load current detection. Since the source current detection used less controlling devices and its structure is simple, so it is more attractive.

REFERENCES

[1] Lucian Asiminoaei, Frede Blaabjerg, Steffan Hansen, "Evaluation of Harmonic Detection Methods for Active Power Filter Applications," IEEE Applied Power Electronics Conference and Exposition, Vol. 1, pp.635 – 641, 2005.

[2] Domenico Casadei, Gabriele Grandi,Ugo Reggiani and Claudio Rossi, "Control Methods for Active Power Filters with Minimum Measurement Requirements," IEEE APEC , Vol. 2, pp.1153-1158, 1999.

[3] Luis A.Mořan,Juan W. Dixon, and Rogel R. Wallace, "A three- Phase Active Power Filter Operating with Fixed Switching Frequency for Reactive Power and Current Harmonic Compensation," IEEE Transactions on Industrial Electronics, Vol. 42, No.4, pp.402-408, 1995.

[4] F.Z.Peng, and J.H.Lai, "Generalized Instantaneous Reactive Power Theory for Three–Phase Power Systems, " IEEE Transaction on Instrumentation and Measurement, Vol.45, pp.293-297, 1996.

[5] Junfei Hu, Fang Zhuo,Zhao'an Wang. "Shunt Active Power Filter with ADMC330", IEEE Power Electronic and Motion Control, Vol. 3, pp.1371-1375, 2000.

[6] H.H.Kuo, S.N.Yeh, and J.C.Hwang, "Novel Analytical Model and Implementation of Three-phase Active Power Filter Controller, " in Proc. IEEE Electric Power Application, Vol.148, No.4, July 2001, pp.369-383.