Design and Application of a Passive Filter Control System

Jeong-Chay Jeon †, Jae-Geun Yoo* and Sang-Ick Lee**

Abstract - The passive filter is economic and efficient in suppressing harmonics but it may cause resonance problems and its performance is constantly dependent on power system impedance or working conditions of loads. This paper presents the DSP (Digital Signal Processor)-based control system, which automatically controls the passive filter in order to solve these problems. The control system can automatically control the passive filter according to working conditions of loads and measured harmonics, reactive power, power factor and so on. Experimental results in the power system using the 100HP DC motor drive are presented in order to verify the performance of the control system.

Keywords: digital signal processor (DSP), harmonics, passive filter, resonance

1. Introduction

Recently, accidents involving electric equipment and economical loss by power quality deterioration related to harmonics show a rising tendency. Proliferation of power electronics loads in the electrical power system produce harmonics distortion as well as many other troubles. In particular, motor drives among nonlinear loads produce a significant amount of harmonics during power converting processing and induce many obstacles [1-3].

Active and passive filters could be considered as concrete countermeasures to suppress harmonics [4-6]. Active filters, which are based on non-sinusoidal currents to meet the harmonic current requirement of the nonlinear load, have become an attractive harmonic countermeasure in recent years. However, the costs involved are quite high. Passive filters, providing a shunt path of low impedance to the harmonic frequencies, generally experience many problems such as harmonic amplification and the fact that its performance is constantly dependent on system impedances. There is also the probability of generating series or parallel resonance with the power system [7], but if those problems are solved, passive filters could be considered as a harmonic countermeasure due to their low cost.

In order to solve the problems in dealing with passive filters, this paper developed a control system to automatically control the passive filter according to operating conditions of loads, along with a program to monitor operating states of the passive filter as well as the control system, harmonics, power factor, voltage, and current in the power system. The passive filter control system was tested in an actual power system using a 100HP DC motor to produce an automobile soundproofing material and its efficiency was verified by analyzing current waveforms, current magnitude, current harmonics magnitude and reactive power according to operating conditions of the DC motor.

2. Passive Filter

Passive filters are largely classified into a tuned filter to eliminate low order harmonics and a high pass filter to eliminate high order harmonics (e.g. 17th up), and its constitution example and impedance variation with frequency are illustrated in Fig.s 1 and 2. The parameter to be considered prior to the selection of R, L and C during passive filter design is the quality factor (Q), and the quality factor determines the sharpness of tuning. In this respect filters may either be of high Q type or low Q type. The high Q type filter is sharply tuned to one of the lower harmonic frequencies and a typical value is between 30 and 60. The low Q type filter, typically in the region of 0.5 ~ 5, has a low impedance over a wide range of frequencies [1].

A single tuned filter as shown in Fig. 1 consists of a series R-L-C circuit and is generally tuned to a lower characteristic harmonic. Its impedance (Z_f) and quality factor are given by equations (1) and (2), which at the resonant frequency (X_0) reduces to R

$$Z_f = R + j\left(wL - \frac{1}{wC}\right) \tag{1}$$

$$Q = \frac{X_0}{R} \tag{2}$$

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Received: April 29, 2004 Accepted: August 24, 2004

where X_0 is reactance of inductor or capacitor in ohms at the tuned frequency, and it is given by equation (3).

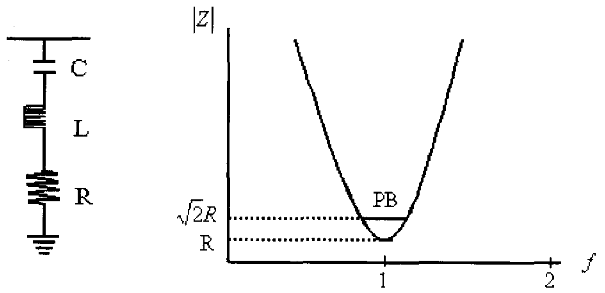
$$X_0 = w_n L = \frac{1}{w_n C} = \sqrt{\frac{L}{C}} \tag{3}$$

where w_n is tuned angular frequency in radians per second.

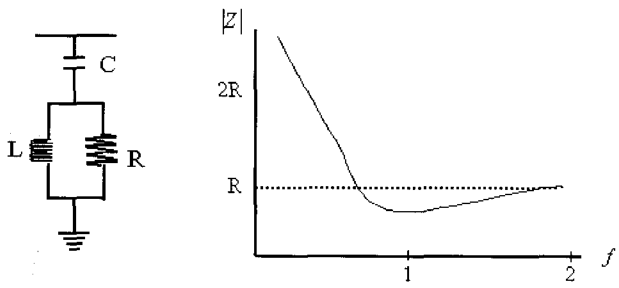
In the high pass filter as shown in Fig. 2, impedance and quality factor (Q) are equations (4) and (5) respectively.

$$Z_f = \left(\frac{1}{R} + \frac{1}{jwL}\right)^{-1} - \frac{1}{jwC} \tag{4}$$

$$Q = \frac{R}{w_n L} = \frac{R}{X_0} \tag{5}$$



(a) Circuit diagram (b) Impedance versus frequency
Fig. 1 Single tuned filter and characteristics



(a) Circuit diagram (b) Impedance versus frequency
Fig. 2 Second-order high-pass filter and characteristics

3. Passive Filter Control System

3.1 The necessity of the passive filter control system

The passive filter is used to suppress harmonics in the electrical power system, which basically consists of capacitors and inductors, with set resonant frequency corresponding to harmonics. Although the passive filter is designed and produced by considering several conditions such as the harmonic field data, power system impedance, frequency fluctuation, filter size and target values of harmonic repression, the effects of the passive filter could be changed according to operating conditions of the loads. Consider a power system using single harmonic load (DC motor drive) and several general loads as shown in Fig. 3 or several harmonic loads and general loads as shown in Fig. 4.

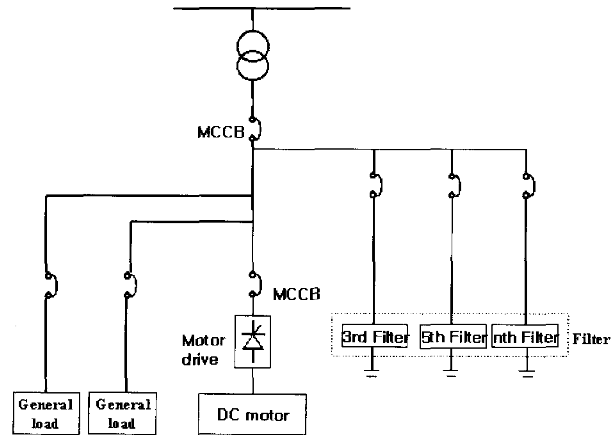


Fig. 3 Single harmonic load

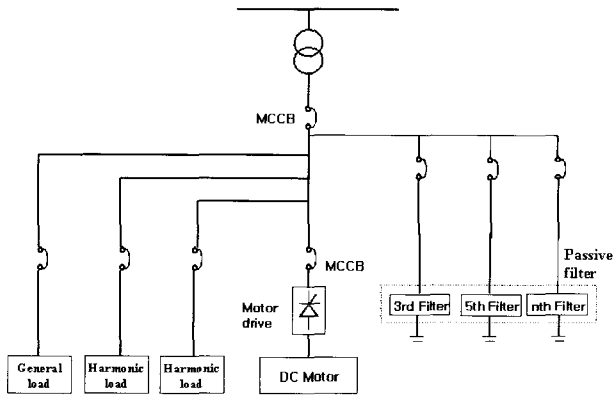


Fig. 4 Harmonic loads of the majority

In the case of Figs. 3 and 4, it is essential to control the passive filter according to operating conditions of harmonic loads, harmonic magnitude and reactive power, power factor and so on. Because the lead power factor in the power system is generated by compensation of the reactive power of the passive filter when some harmonic generation loads are stopped, there are concerns regarding the increase of power losses of the power system and transformer, and rise of power system voltage.

In particular, in the event that power system impedance is varied and the harmonic component in the power source is included, there is a need to protect the filter by monitoring it because of series and parallel resonance problems. The passive filter must be controlled to avoid overload of the other branches when troubles with some branches of the passive filter are generated.

3.2 The development of the passive filter control system

The passive filter control system, which is proposed in this paper, consists of a signal input voltage component, current measuring sensor and filter, A/D conversion part converting analog signal into digital signal, digital signal processing element controlling circumference installations and performing operation functions, PLD part performing system interface processing, memory component of SRAM and FROM, operation power source element supplying operation power and an output part sending signals to control the passive filter as shown in Fig. 5.

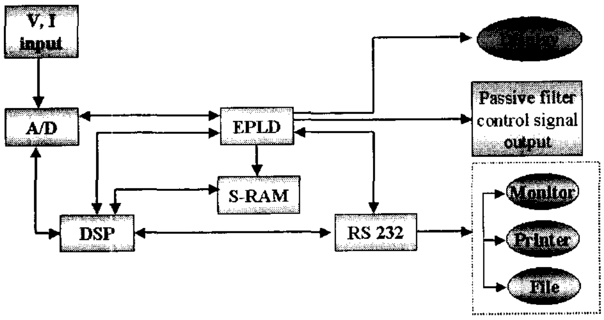
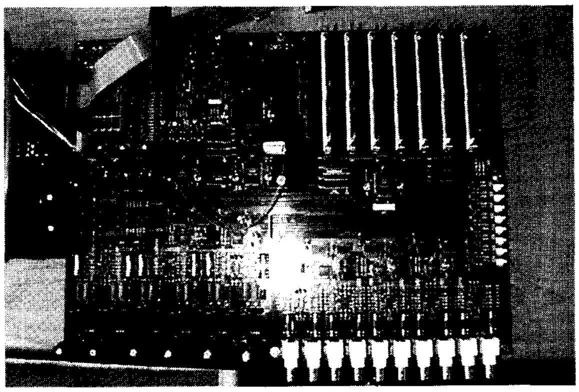


Fig. 5 Block-diagram of passive filter control system

The passive filter control system in Fig. 5 adjusts the analog signal into a signal suitable to the A/D converter after inputting voltage and current signal by voltage and current sensor and converting it into digital signal by the A/D converter. In order to simultaneously convert the analog signal of voltage 8 and current 10 channel into a digital signal, the A/D conversion component was designed using Analog Devices's 14bit A/D converter AD 7865 having an analog input 4 channel of AC level and conversion start signal input ability. In addition the control system guarantees security in the case of any trouble using 8bit bi-directional buffer 74F245 between the DSP and A/D converter in order to limit only the element in the event of element trouble occurring in the address and data bus of the A/D conversion component.

A/D converted data is transmitted to TMS320C32 DSP of the digital signal processing part, and DSP performs frequency analysis by Fourier conversion on each cycle of voltage and current, and calculates power (active, reactive and apparent power), power factor and so on. And interface between DSP and external digital elements use Altera's EPLD (Erasable/ Programmable Logic Device) EMP7128.

Also, in order to save measured data and quickly perform processor programming, the memory block is designed by connecting 4Mbit S-RAM K6R4008 in serial and parallel. These memory blocks are set up in the control system PCB (Printed circuit board) using a 72 pin SIMM socket. The program memory of the DSP is designed by using AMD's FROM 29F040. Picture 1 shows the PCB hardware of the passive filter control system.



Pic. 1 Passive filter control system PCB

3.3 Program development

In order for the user to confirm data measured by the passive filter control system and to analyze that data, the computer program using Borland's C++ Builder is developed. Figs. 6 and 7 show the main window formation

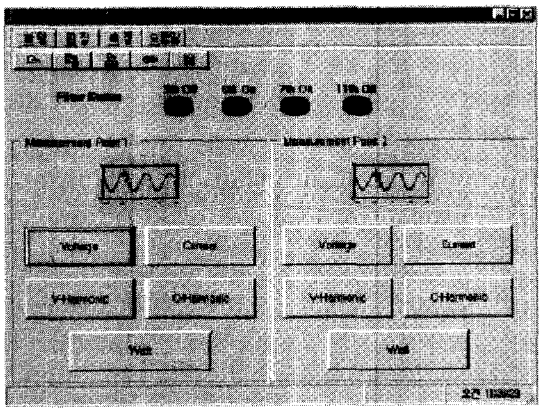


Fig. 6 Main window of the control system program

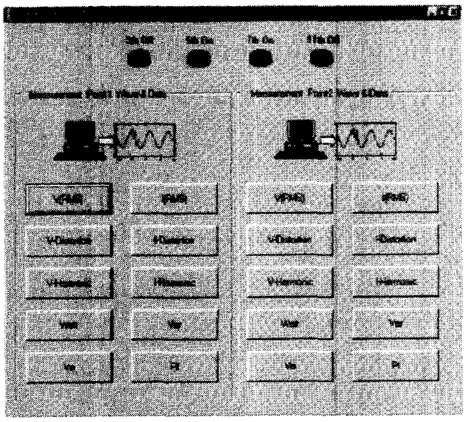


Fig. 7 Analysis window of the control system program

of the computer program and it is possible that the user can confirm the operation state of the passive filter, as well as waveform and data of voltage, current, percentage voltage distortion, percentage current distortion, power (active, reactive and apparent power) and power factor of measuring points separated as load and source parts.

4. Test of the passive filter control system

4.1 The development of a passive filter

Approximately a 27kVAR passive filter to apply and test the passive filter control system was developed based on the harmonics generated by the DC motor drive of Fig. 7. The passive filter consists of a tuned filter for third, fifth, seventh order and a high-pass filter for the 11th and high orders. SSR (Solid State Relay) was used to switch each branch of the passive filter by the signal outputted in the passive filter control. Table 1 lists the design and production specifications of the passive filter.

Table 1 Passive filter design and production specification

Section	Third order	Fifth order	Seventh order	Hi-pass
Capacitor (kVAR)	6.1	5.7	5.5	10
Inductor (mH)	2.6	0.95	0.4	0.09
SSR (A)	30	50	40	50
Others	V-meter, A-meter, FAN, etc.			

4.2 Field test of the passive filter and control system

As shown in Fig. 8, the control system developed in this paper was connected with a passive filter in the power system using a 100HP DC motor, an extruding machine, an air blower, other loads, and the control passive filter according to operation conditions of the DC motor. The power system of Fig. 8 used a DC motor to produce automobile soundproofing material, and it was difficult to optimize effects of the passive filter due to repeated start and stop of the DC motor, frequent variation of operating conditions and so on. Picture 2 shows the field test scene of the control system.

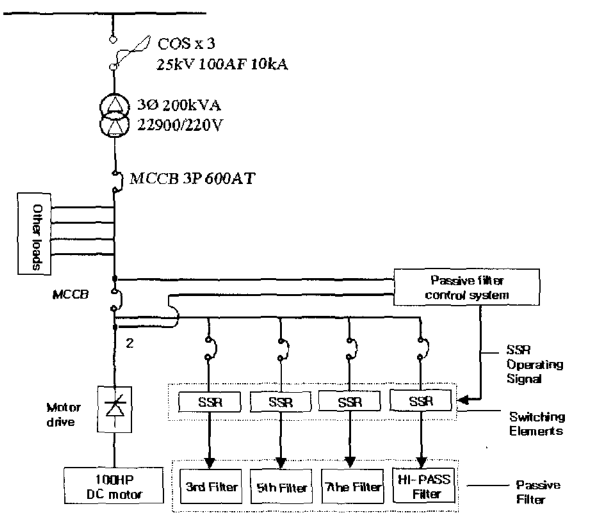
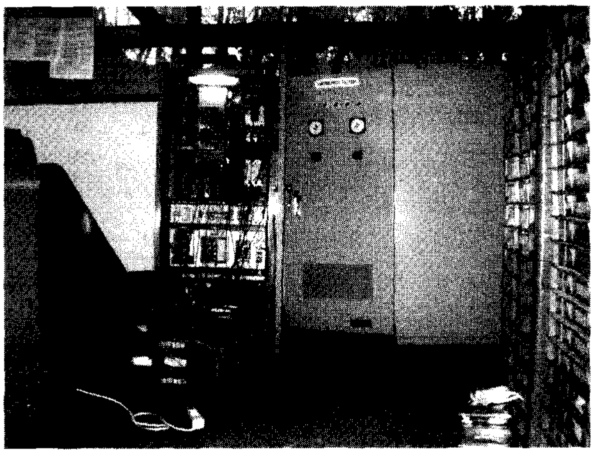


Fig. 8 Wiring diagram of the passive filter control system

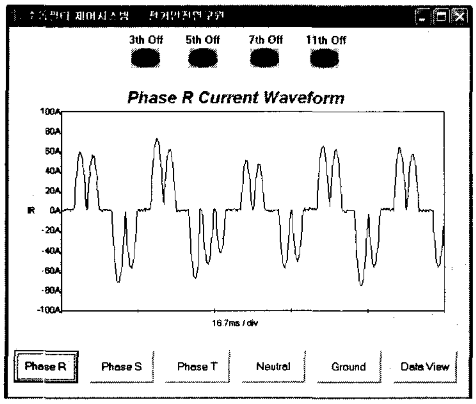


Pic. 2 Field test scene

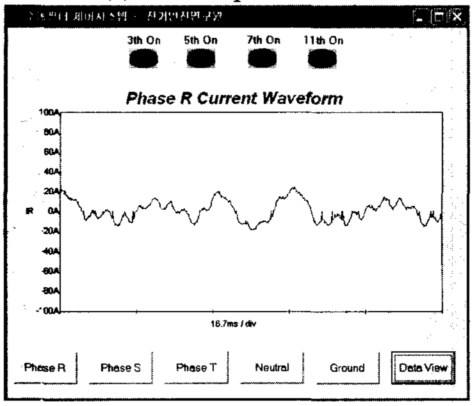
4.2 Results

Fig. 9 indicates the current waveforms of source part (point 1 of Fig. 8) measured by the control system and expressed by the window program in this work. The current waveform of Fig. 8(a) without the passive filter is distorted and although it is not a prefect sine wave, the current waveforms of Fig.s 8(b) and (c) with passive filter and control system are similar to a sine wave. However, it is difficult to confirm the effects of the control system by waveform.

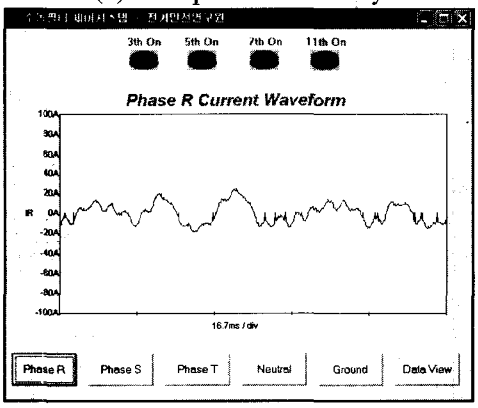
Fig. 10 shows current amplitude variation of source part (point 1 of Fig. 8) according to time. In Fig. 10(a) without the passive filter, the power system current is 40A when the motor is operated. In Fig. 10(b) with the passive filter having no regard to operating conditions of the DC motor, the current is reduced from 40A to 10A by harmonic current compensation effectiveness of the passive filter when the motor is being operated, but reactive current is about 40A by passive filter impedance when the motor is stopped. In Fig. 10(c), the current is reduced to 10A by compensating the harmonic current because the passive filter is automatically closed by the control system when the DC motor is operated. There is no reactive current after a set time because the passive filter is automatically opened by the control system after a set time (five minutes according to the operating pattern of the DC motor in this paper) when the DC motor is stopped.



(a) Without passive filter

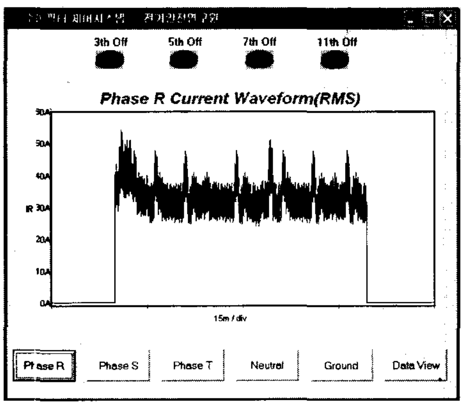


(b) With passive filter only

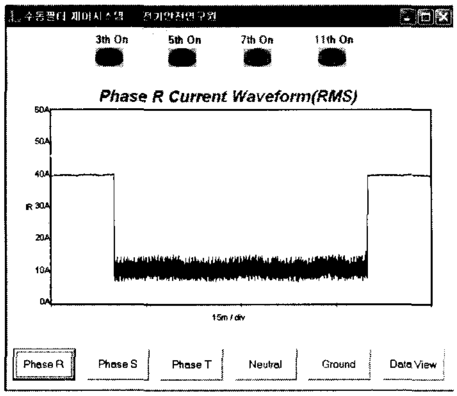


(c) With passive filter and control system

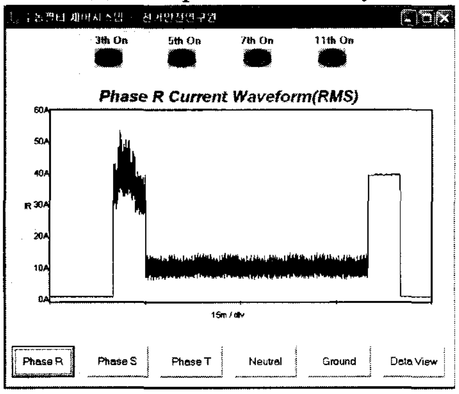
Fig. 9 Current Waveforms



(a) Without passive filter



(b) With passive filter only

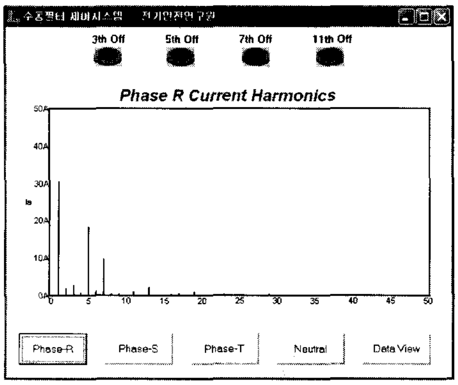


(c) With passive filter and control system

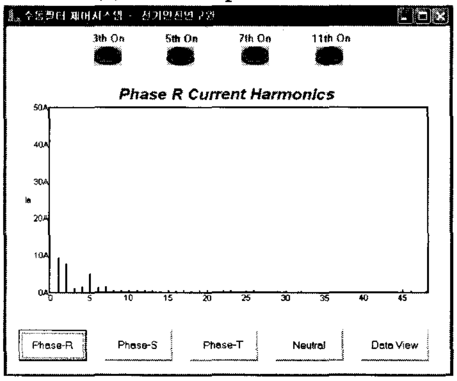
Fig. 10 Variation of current magnitude

Fig. 11 displays the current harmonic amplitude spectrum of the source part. 5th harmonic current is about 18A and 7th harmonic current is about 10A as shown in Fig. 11(a) without the passive filter. Fundamental wave currents decrease and 5th harmonic current is reduced from 18A to 8A and 7th harmonic current is reduced from 10A to 5A after being compensated by the passive filter and control system as shown in Figs. 11(b) and 11(c).

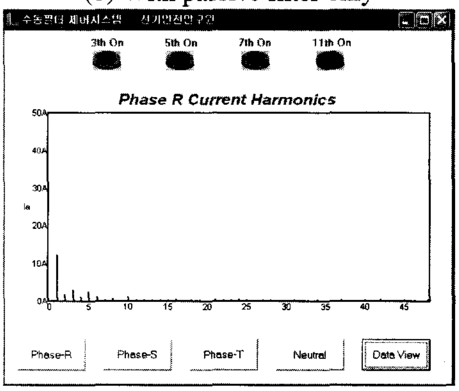
Fig. 12 shows reactive power magnitude variation of source part according to motor operation condition variation. In Fig. 12(a) without the passive filter, reactive power is about 25kVAR when the motor is operated. In Fig. 12(b) with the passive filter having no regard to operating conditions of the DC motor, reactive power is reduced form 25kVAR to 5kVAR by compensation effectiveness of the passive filter when the motor is operated, but reactive power is about 23kVAR by the passive filter when the motor is stopped. In Fig. 12(c), because the passive filter is automatically closed by the control system when the DC motor is being operated, reactive power is reduced to 5kVAR by compensation effectiveness of the passive filter. Also, there is no reactive power after a set time because the passive filter is automatically opened by the control system after a set time (five minutes according to the operating pattern of the DC motor in this paper) when the DC motor is stopped.



(a) Without passive filter

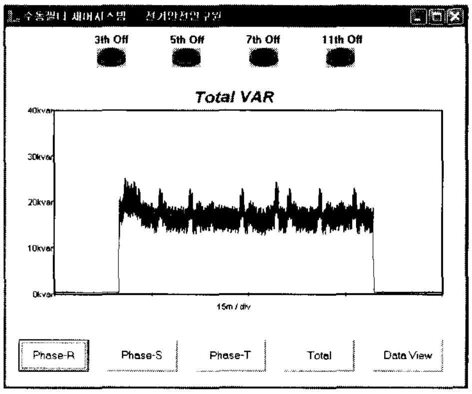


(b) With passive filter only

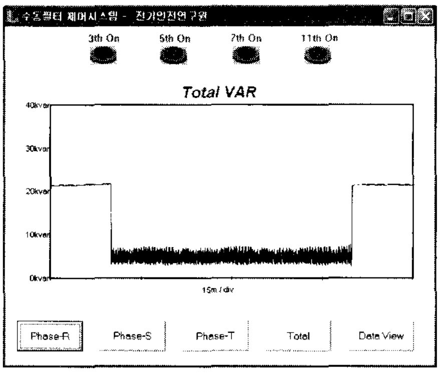


(c) With passive filter and control system

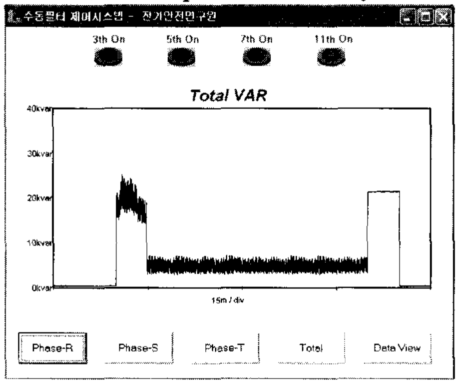
Fig. 11 Spectrum of current harmonics



(a) Without passive filter



(b) With passive filter only



(c) With passive filter and control system

Fig. 12 Variation of reactive power magnitude

5. Conclusion

This work developed a passive filter control system that can automatically control the passive filter according to operating conditions of loads, harmonics, reactive power, power factor and so on. The window program, which can monitor the operation state of the control system and the passive filter and analyze the voltage, current, harmonics, power (active, reactive and apparent power) and power factor measured by the control system, is developed.

The passive filter control system was tested with the passive filter in the power system using the 100HP DC motor and general loads, and test results were confirmed using the developed program. Test results illustrated that the control system suppressed the occurrence of reactive current and power by automatically opening the passive filter when the DC motor is stopped and reduced reactive power and harmonic currents by automatically closing the passive filter when the DC motor is operated.

Also, it is judged that the passive control system could solve both the over compensation problem of reactive power and the resonance problem with the power system by automatically controlling the passive filter. Although it is not tested in this paper, it is expected that the passive filter control system could be applied in the power systems having several harmonic loads and several passive filters.

Acknowledgements

This work was supported by the Electric Power Industry R&D Program of MOCIE.

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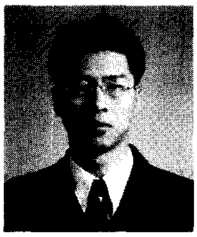

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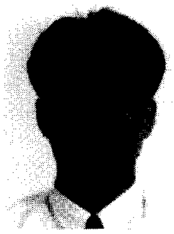

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