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A New Power Line Conditioner for Harmonic Compensation in Power Systems

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Abstract – This paper proposes a new power line conditioner consisting of two small rating series active filters and a shunt passive filter. The power line conditioner aims at a general filtering system which will be installed at the point of common coupling in a power system feeding harmonic-sensitive loads and unidentified harmonic-producing loads. One of the two active filters is connected in series with the supply, while another is in series with the shunt passive filter. The purpose of the power line conditioner is to reduce voltage distortion at the connection point, and is to eliminate harmonic currents escaping into the system upstream of the connection point.

A control scheme of the two series active filters which play an important role is described in this paper. Its filtering characteristics are discussed with the focus on voltage and current distortion. A prototype model of 20kVA is constructed to verify the functionality and performance of the power line conditioner.

I. INTRODUCTION

Harmonic pollution caused by nonlinear loads has been a serious problem with the proliferation of diode or thyristor rectifiers and cycloconverters in industrial applications and transmission/distribution systems. Due to a finite amount of supply impedance, voltage distortion at the point of common coupling results from harmonic currents produced by the nonlinear loads.

Passive filters consisting of tuned LC filters and/or high pass filters have traditionally been used to improve power factor and to absorb harmonics in power systems because of their simplicity, low cost and high efficiency. A tuned LC filter should be designed to exhibit lower impedance at a tuned harmonic frequency than the supply impedance, so that almost all harmonic current at the harmonic frequency enters the LC filter. In principle, filtering characteristics of a passive filter are determined by the impedance ratio of the supply and the passive filter. Therefore, it is difficult for the passive filter installed in the vicinity of a harmonic-producing load, which is connected to a fairly stiff ac supply, to meet the above design criteria. In addition, the passive filter has the following drawbacks:

- The background voltage distortion on the utility supply may overload the passive filter. In the worst case, the passive filter may fall in series resonance with the supply impedance.
- At a specific frequency, the passive filter may fall in parallel resonance with the supply impedance, so that amplification of the harmonic current occurs and the currents in the supply and the passive filter may be excessive.

Active filters, which are classified into shunt and series ones, have been researched to compensate for reactive power, negative-sequence, harmonics, and/or flicker in industrial power systems since their basic compensation principles were proposed in the 1970's [1]–[3]. However, there was almost no advance in active filters beyond the laboratory testing stage since at that time circuit technology was too poor to practically implement the compensation principles. Recent progress in voltage-current rating and switching speed of semiconductor power devices such as IGBTs and GTO thyristors has spurred interest in the study of active power filters with the focus on practical applications. Sophisticated PWM inverter technology, along with the so-called "pq-theory" [4], has made it possible to put them into a commercial stage in Japan [5]–[7].

In 1982, a shunt active filter of 800kVA, which consists of current-source PWM inverters using GTO thyristors, was put into practical use for harmonic compensation [5]. In 1986, a combined system of a shunt active filter of 900kVA, comprising voltage-source PWM inverters using bipolar junction transistors, and a shunt passive filter of 6600kVA was installed to absorb harmonics generated by large capacity cycloconverters for steel mill drives [7]. In 1991, a shunt active filter of 20MVA, consisting of voltage-source PWM inverters using GTO thyristors, was developed for flicker compensation for arc furnaces with the help of a shunt passive filter of 20MVA [8]. Although the research on active filters has been done by many researchers, almost all the published papers have dealt with active filters installed in the vicinity of an identified harmonic-producing load at the end terminal in a power system [9].

A new power line conditioner proposed in this paper is intended to be installed at the point of common coupling in a power system feeding harmonic-sensitive loads and unidentified harmonic-producing loads. The power line conditioner is characterized by the system configuration consisting of two small rating series active filters and a shunt passive filter.

In this paper, a control scheme of the two series active filters is described, based on the hybrid passive-series active filter which has been already proposed by the authors [10], [11]. Some interesting experimental results obtained from a prototype model of 20kVA are shown to verify the functionality and performance of the proposed power line conditioner.

II. SYSTEM CONFIGURATION

Fig.1 shows an experimental power system and a circuit diagram of a new power line conditioner enclosed with a broken line. The main circuit of the power line conditioner consists of two active filters AF1 and AF2, matching transformers of turn ratio 1:20 MT1 and MT2, and a passive filter PF. Active filter AF1 is connected in series with the supply through matching transformer MT1, while active filter AF2 is connected in series with the passive filter through matching transformer MT2. Each active filter of 0.5kVA consists of three single-phase voltage-source PWM inverters using power MOSFETs. The dc terminals of the six single-phase inverters are connected to each other and to a dc capacitor of $2200\mu F$ in parallel. Fig.2 shows a detailed circuit diagram of active filters AF1 and AF2. The passive filter of 8kVA consists of 11th and 13th tuned LC filters and a high pass filter. Table 1 shows the circuit constants of passive filter PF.

A harmonic-sensitive load L1, and two harmonic-producing loads

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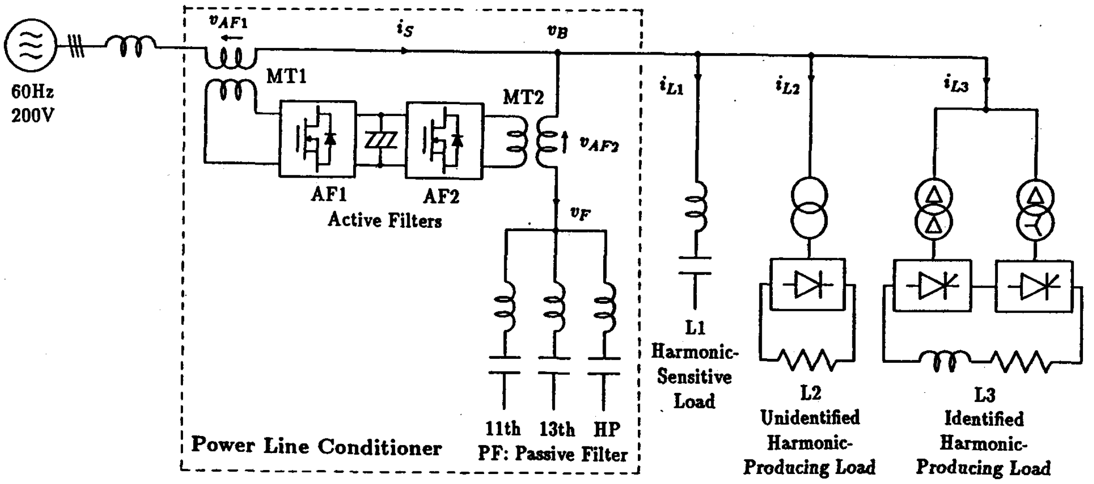

Fig.1. System configuration of power line conditioner.

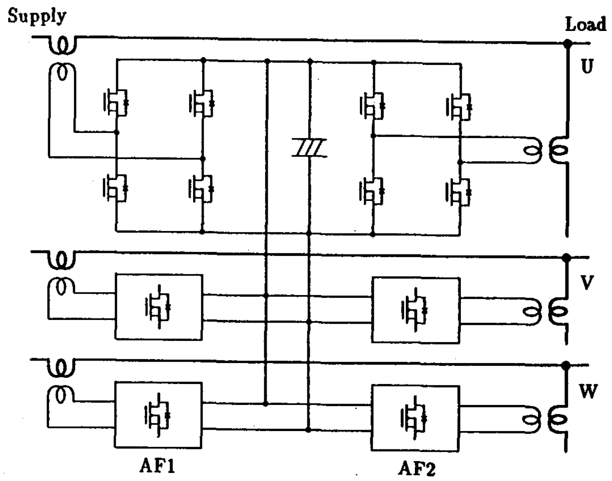

Fig.2. Detailed circuit of active filters.

Table 1. Circuit constants of passive filter.

	inductance	capacitance	Q
11th	380μH	150μF	20
13th	300μH	140μF	20
HP	40μH	260μF	20

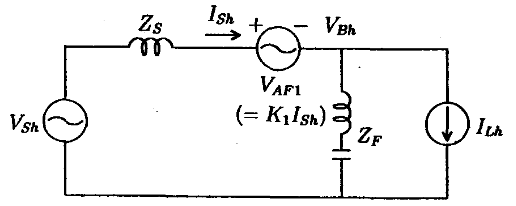

Fig.3. Equivalent circuit of AF1 and PF.

L2 and L3 are connected on a common bus, where the bus voltage v_B is 200V. A three-phase twelve-pulse thyristor rectifier of 20kVA is an identified load L3, which dominantly produces 11th and 13th harmonic currents. On the other hand, a three-phase diode rectifier of 3kVA is an unidentified load L2, which dominantly generates 5th and 7th harmonic currents. Therefore, neither 5th nor 7th tuned LC filters are connected in the specially designed passive filter for this experiment. A power capacitor of 3kVA, with a series reactor of 5% of the capacitor rating, is considered an hypothetical harmonic-sensitive load because voltage distortion at the common bus causes a large amount of harmonic currents to flow in i_{L1}. The supply reactance in Fig.1 is 3% on 200V, 60A, 60Hz, 20kVA base.

In a practical application, a passive filter consisting of 5th and 7th tuned LC filters plus a high pass filter will be used in the power line conditioner because 5th and 7th harmonics are the most dominant in real power systems.

III. CONTROL SCHEME OF ACTIVE FILTERS

A. *Active filter AF1*

Fig.3 shows a harmonic circuit equivalent to a hybrid filter which combines active filter AF1 and passive filter PF; it is represented on a per-phase base. Here, Z_F is the equivalent impedance of the passive filter, and Z_S is the supply impedance. For the sake of simplicity, only a harmonic current source I_{Lh} is assumed in the system downstream of the hybrid filter. A harmonic voltage existing in the system upstream or a background harmonic voltage in the supply, V_{Sh} is also included in Fig.3. Active filter AF1 is assumed as an ideal controllable voltage source V_{AF1}, while active filter AF2 is removed from Fig.3.

Active filter AF1 is controlled in such a way as to present zero impedance to the external circuit at the fundamental frequency and a high resistance K_1 [Ω] at harmonic frequencies. According to references [10] and [11], the command of instantaneous ac voltage of active filter AF1, v^*_{AF1} is given by

$$v^*_{AF1} = K_1 \cdot i_{Sh} \tag{1}$$

Here, i_{Sh} is the harmonic current in the supply, and K_1 is a high gain which has the dimension of Ω. It should be noted that the resistance K_1 in Fig.3 is identical to the gain K_1 in (1). If K_1 is ∞ under an ideal control condition, the supply harmonic current I_{Sh}, the bus harmonic voltage V_{Bh}, and the ac voltage of active filter AF1, i.e., V_{AF1} are easily obtained from Fig.3.

$$I_{Sh} = 0 \tag{2}$$

$$V_{Bh} = -Z_F I_{Lh} \tag{3}$$

$$V_{AF1} = V_{Sh} + Z_F I_{Lh} \tag{4}$$

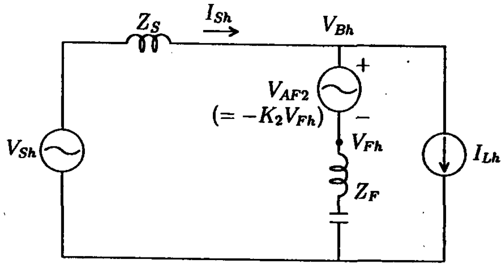

Fig.4. Equivalent circuit of AF2 and PF.

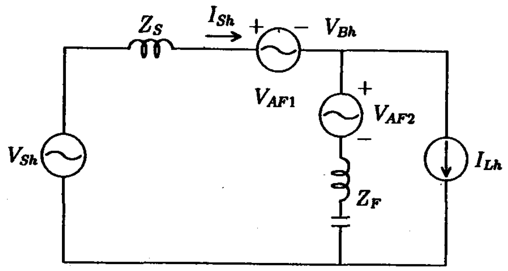

Fig.5. Equivalent circuit of AF1, AF2 and PF.

No harmonic current flows in the supply because the passive filter absorbs all the load harmonic current I_{Lh}. In addition, V_{Sh} disappears on the common bus because active filter AF1 cancels it as shown in the first term on the right side of (4). However, a harmonic voltage $Z_F I_{Lh}$ appears due to the existence of voltage drop between Z_F and I_{Lh}. The combined filter shown in Fig.3 has the following drawback:

- If I_{Lh} contains harmonic components having unspecified frequencies other than tuned frequencies in the passive filter, a relatively large amount of harmonic voltage would occur on the bus.

B. *Active filter AF2*

Fig.4 shows a harmonic circuit equivalent to a hybrid filter which combines active filter AF2 and passive filter PF. Active filter AF2 is assumed as an ideal controllable voltage source V_{AF2}, while active filter AF1 is removed from Fig.4. Active filter AF2 is controlled in such a way as to present zero voltage to the external circuit at the fundamental frequency and a harmonic voltage at harmonic frequencies. The command of instantaneous ac voltage of active filter AF2, v^*_{AF2} is given by

$$v^*_{AF2} = -K_2 \cdot v_{Fh} \tag{5}$$

Here, K_2 is a gain and v_{Fh} is a harmonic voltage existing in the terminal voltage across the passive filter. The total equivalent impedance of active filter AF2 and passive filter PF, which are connected to each other in series, is obtained from Fig.4.

$$Z_{AF} = (1-K_2)Z_F \tag{6}$$

Active filter AF2 has the ability to cancel the harmonic voltage which appears due to the non-negligible impedance of passive filter PF, thus providing a low impedance branch of harmonic currents. Since K_2 is unity under an ideal control condition, I_{Sh}, V_{Bh}, and V_{AF2} are given by

$$\begin{aligned} I_{Sh} &= \frac{V_{Sh}}{Z_S} && (7)\\ V_{Bh} &= 0 && (8)\\ V_{AF2} &= -\frac{Z_F}{Z_S}V_{Sh} + Z_F I_{Lh} && (9) \end{aligned}$$

Since $V_{Bh}=0$, no harmonic voltage occurs on the bus. Moreover, no harmonic current escapes from the system downstream into the system upstream because I_{Lh} is excluded from (7). However, the combined filter in Fig.4 has the following drawback:

- If the combined filter is connected to a fairly stiff ac supply including a background harmonic voltage V_{Sh}, a large amount of harmonic current, which is expressed by V_{Sh}/Z_S, would flow from the supply into active filter AF2 and passive filter PF.

IV. FILTERING CHARACTERISTICS

Fig.5 shows an equivalent circuit to harmonics of the power line conditioner proposed in this paper. The commands for instantaneous ac voltages of active filters AF1 and AF2 are given by (1) and (5), respectively. As a result, the filtering characteristics of the power line conditioner are obtained from Figs.3 and 4.

$$\begin{aligned} I_{Sh} &= \frac{1}{Z_S+K_1+(1-K_2)Z_F}V_{Sh}\\ &\quad+\frac{(1-K_2)Z_F}{Z_S+K_1+(1-K_2)Z_F}I_{Lh} \end{aligned} \tag{10}$$

$$\begin{aligned} V_{Bh} &= \frac{(1-K_2)Z_F}{Z_S+K_1+(1-K_2)Z_F}V_{Sh}\\ &\quad-\frac{(Z_S+K_1)(1-K_2)Z_F}{Z_S+K_1+(1-K_2)Z_F}I_{Lh} \end{aligned} \tag{11}$$

$$\begin{aligned} V_{AF1} &= \frac{K_1}{Z_S+K_1+(1-K_2)Z_F}V_{Sh}\\ &\quad+\frac{K_1(1-K_2)Z_F}{Z_S+K_1+(1-K_2)Z_F}I_{Lh} \end{aligned} \tag{12}$$

$$\begin{aligned} V_{AF2} &= -\frac{K_2 Z_F}{Z_S+K_1+(1-K_2)Z_F}V_{Sh}\\ &\quad+\frac{K_2(Z_S+K_1)Z_F}{Z_S+K_1+(1-K_2)Z_F}I_{Lh} \end{aligned} \tag{13}$$

If the ideal control conditions ($K_1=\infty$ and $K_2=1$) are assumed, equations (10) ~ (13) are changed into the followings.

$$\begin{aligned} I_{Sh} &= 0 && (14)\\ V_{Bh} &= 0 && (15)\\ V_{AF1} &= V_{Sh} && (16)\\ V_{AF2} &= Z_F I_{Lh} && (17) \end{aligned}$$

The ac voltage of active filter AF2 cancels the harmonic voltage appearing across passive filter PF, thus providing a harmonic current branch with zero impedance. Because all the harmonic currents produced downstream enter passive filter PF, no harmonic current escapes upstream. On the other hand, the ac voltage of active filter AF1 compensates for the background harmonic voltage, thus blocking the flow of harmonic currents from the supply into the passive filter. Accordingly, no harmonic voltage occurs on the bus as shown in (15). It is concluded that the power line conditioner proposed in this paper has the following functionality.

- Active filters AF1 and AF2 are controlled so as to actively shape both the bus voltage v_B and the supply current i_S into sinusoid with the help of passive filter PF.

The power line conditioner, therefore, is useful for harmonic compensation in a power system feeding harmonic-sensitive loads and unidentified harmonic-producing loads.

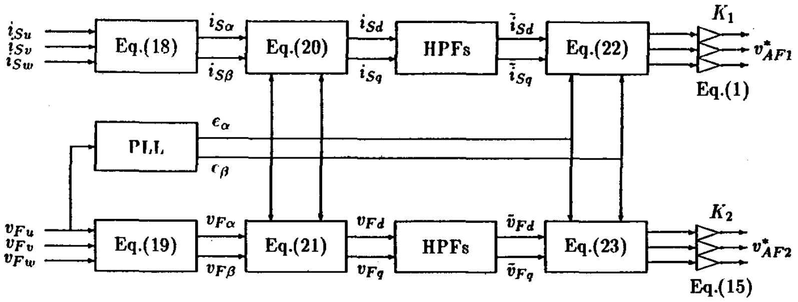

Fig.6. Control circuit.

V. Control Circuit

Fig.6 shows a control circuit which is developed for the following experiment. Three-phase supply currents and terminal voltages across passive filter PF in Fig.1 are changed into two-phase ones on the $\alpha\beta$ coordinates.

$$\begin{bmatrix} i_{S\alpha} \\ i_{S\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{Su} \\ i_{Sv} \\ i_{Sw} \end{bmatrix} \tag{18}$$

$$\begin{bmatrix} v_{F\alpha} \\ v_{F\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_{Fu} \\ v_{Fv} \\ v_{Fw} \end{bmatrix} \tag{19}$$

The dq-transformation is achieved in terms of two-phase sinusoidal signals $\cos\omega t$ and $\sin\omega t$ which are generated by the phase locked loop circuit. Here, ω is the angular frequency of the supply.

$$\begin{bmatrix} i_{Sd} \\ i_{Sq} \end{bmatrix} = \begin{bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{bmatrix} \begin{bmatrix} i_{S\alpha} \\ i_{S\beta} \end{bmatrix} \tag{20}$$

$$\begin{bmatrix} v_{Fd} \\ v_{Fq} \end{bmatrix} = \begin{bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{bmatrix} \begin{bmatrix} v_{F\alpha} \\ v_{F\beta} \end{bmatrix} \tag{21}$$

For instance, dc components in i_d and i_q correspond to positive-sequence fundamental components in i_α and i_β because the dq-transformation is considered a kind of frequency changer. By introducing four 1st-order high-pass filters HPFs, their ac components $\tilde{i}_{Sd}$, $\tilde{i}_{Sq}$, $\tilde{v}_{Fd}$, and $\tilde{v}_{Fq}$ are extracted from i_{Sd}, i_{Sq}, v_{Fd}, and v_{Fq}, respectively. The cut-off frequency of high-pass filters HPFs in Fig.6 is set to be 1Hz in this experiment. The inverse-transformation of (18) ~ (21) gives three-phase harmonic currents and voltages as shown in the following equations;

$$\begin{bmatrix} i_{Shu} \\ i_{Shv} \\ i_{Shw} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{bmatrix}^{-1} \begin{bmatrix} \tilde{i}_{Sd} \\ \tilde{i}_{Sq} \end{bmatrix} \tag{22}$$

$$\begin{bmatrix} v_{Fhu} \\ v_{Fhv} \\ v_{Fhw} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{bmatrix}^{-1} \begin{bmatrix} \tilde{v}_{Fd} \\ \tilde{v}_{Fq} \end{bmatrix} \tag{23}$$

Amplification of the calculated harmonic currents and voltages by the gain of K_1 and K_2 produces the commands for instantaneous ac voltages of the voltage-source PWM inverters. Comparison of each command with a carrier signal of a triangular waveform determines the switching pattern of power MOSFETs. The control circuit designed and fabricated in this paper is based on a hybrid analog-digital circuit.

VI. Experimental Results

As discussed earlier, the ideal gain of active filter AF1 is $K_1 = \infty$ and that of active filter AF2 is $K_2 = 1$. In this experiment, however, K_1 is set to 2.2Ω (= 100% on 200V 60A 20kVA base), and K_2 to 0.8 in order to avoid the instability of operation which may be caused by a time delay in detection and calculation by the control circuit. Although the gains are experimentally decided in this paper, the relationship between the gains and the impedances will be made clearer in the next stage. The dc voltage of the capacitor connected to the dc terminals of six voltage-source PWM inverters is 120V, and the frequency of the carrier signal in the control circuit is 15kHz. No small capacity passive filter is connected as shown in Fig.2 because an amount of leakage inductance in matching transformers MT1 and MT2 plays an important role in reducing the higher frequency harmonic components due to the PWM of the active filters.

Figs.7, 8, and 9 show experimental waveforms in a case of the disconnection of harmonic-producing loads L2 and L3 on the common bus in Fig.1. Table 2 shows the experimental values of harmonics of voltage and current with respect to their fundamental components. Due to the existence of 5th and 7th background harmonic voltages in the supply, 5th and 7th harmonic currents of 3.3% and 9.1% are present in the supply, respectively, as shown in Fig.7. Since neither active filters AF1 nor AF2 are operating, an amount of harmonic voltage appears on the bus, so that a 5th harmonic current of 12% is flowing into the capacitor, i.e., harmonic-sensitive load L1. After active filter AF1 is switched on, the 5th harmonic current is reduced 0.7%, as shown in Fig.8 because active filter AF1 acts as a blocking high resistor at the 5th harmonic frequency. As a result, the harmonics in v_B and i_{L1} are reduced by two-thirds. Even if active filters AF1 and AF2 are operating, AF2 does not generate any voltage, as shown in Fig.9. The reason is that almost no harmonic voltage appears on the bus due to the effect of active filter AF1.

Figs.10, 11, and 12 show experimental waveforms where harmonic-producing loads L2 and L3 are connected. Table 3 shows the experimental values of harmonics, corresponding to Table 1. Neither active filters AF1 nor AF2 are operating in Fig.10. Since neither the 5th nor the 7th tuned LC filter is connected to passive filter PF in Fig.1, 5th and 7th harmonic currents of 3.8% and 1.8%, which are generated by the diode rectifier, i.e. unidentified harmonic-producing load L2,

Table 2. Experimental values in case of disconnection of L2 and L3.

operating	i_S[%]		i_{L1}[%]		v_B[%]	
condition	5th	7th	5th	7th	5th	7th
PF	3.3	9.1	12.	8.3	0.8	1.5
PF + AF1	0.7	0.7	4.4	0.8	0.3	0.0
PF + AF1 + AF2	1.5	0.7	5.2	0.8	0.3	0.2

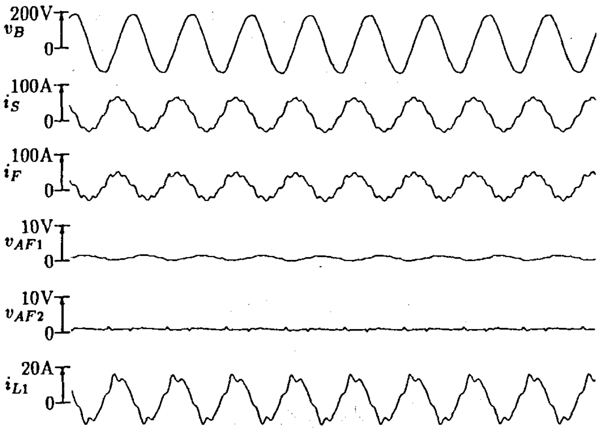

Fig.7. Experimental waveforms (PF).

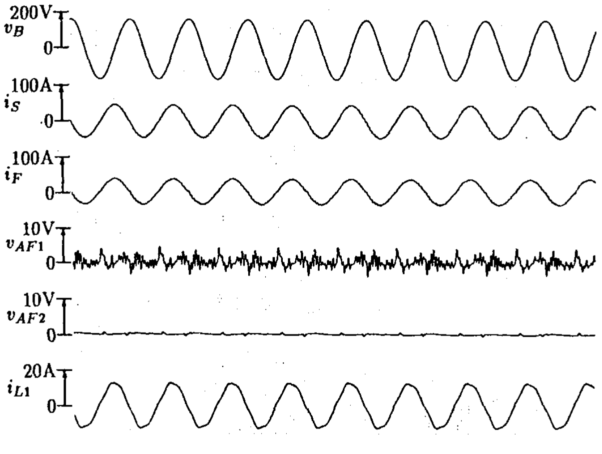

Fig.8. Experimental waveforms (PF + AF1).

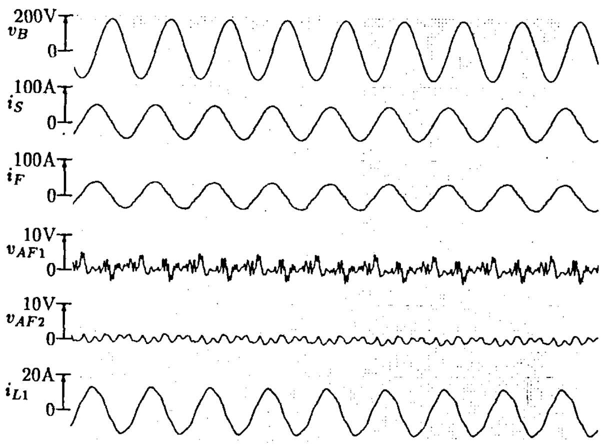

Fig.9. Experimental waveforms (PF + AF1 + AF2).

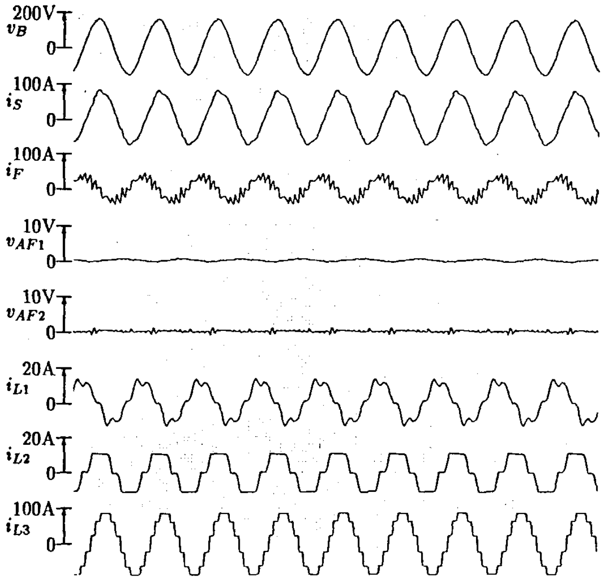

Fig.10. Experimental waveforms (PF).

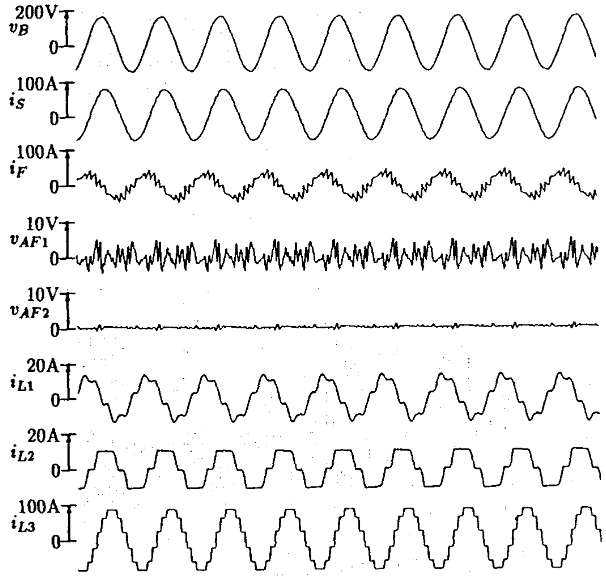

Fig.11. Experimental waveforms (PF + AF1).

Table 3. Experimental values in case of connection of L2 and L3.

operating condition	i_S[%]		i_{L1}[%]		v_B[%]	
	5th	7th	5th	7th	5th	7th
PF	3.8	1.8	21.	5.5	1.4	1.0
PF + AF1	1.1	0.2	20.	2.1	1.4	0.8
PF + AF1 + AF2	1.1	0.2	13.	2.1	1.0	0.8

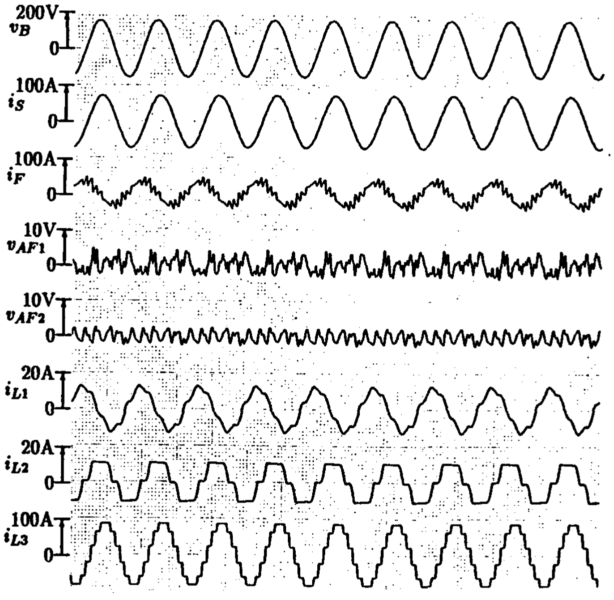

Fig.12. Experimental waveforms (PF + AF1 + AF2).

escape into the supply. A 5th harmonic current of 21% enters capacitor L1 because of the existence of a harmonic voltage of 1.4% in v_B. After active filter AF1 is switched on, the 5th harmonic current in the supply are reduced by three-fourths, so that the current waveform of the supply is almost sinusoidal as shown in Fig.11. However, the 5th harmonic current generated by unidentified harmonic-producing load L2 enters passive filter PF, so that a 5th harmonic voltage of 1.4% appears on the common bus. The 5th harmonic voltage in v_B and the 5th harmonic current in i_{L1} are nearly equal to those using only passive filter PF. This means that harmonic interference still exists between harmonic-sensitive load L1 and unidentified harmonic-producing load L3. After active filters AF1 and AF2 are switched on, the 5th harmonic voltage in v_B and the 5th harmonic current in i_{L1} are reduced 1.0% and 13%, respectively, as shown in Table 3.

VII. CONCLUSIONS

A new power line conditioner consisting of two small rating series active filters and a shunt passive filter has been proposed in this paper. It is capable of compensating for harmonics of supply currents and bus voltages, so that no harmonic interference occurs between harmonic-producing loads and harmonic-sensitive loads which are connected on the common bus. The LC filters used in this experiment are tuned at the 11th and 13th harmonic frequencies in order to verify the effect of reduction of 5th and 7th harmonics.

In a practical application, 5th and 7th tuned LC filters plus a high pass filter will be adopted as a passive filter because 5th and 7th harmonic voltages and currents are the most dominant in real power systems. A power line conditioner composed of the passive filter and two active filters can greatly reduce not only 5th and 7th harmonics but also non-canonical harmonics or non-characteristic harmonics such as 4th harmonics.

REFERENCES

[1] H. Sasaki, T. Machida, "A new method to eliminate ac harmonic currents by magnetic compensation - Considerations on basic design", IEEE Trans. Power Appr. Syst., vol.90, no.5, pp.2009-2019, 1971.

[2] L. Gyugyi, E. C. Strycula, "Active ac power filters", IEEE/IAS, Annual Meeting, pp.529-535, 1976.

[3] N. Mohan, et al, "Active filters for ac harmonic suppression", IEEE/PES Winter Meeting, 1977, A77026-8.

[4] H. Akagi, Y. Kanazawa, A. Nabae, "Instantaneous reactive power compensators comprising switching devices without energy storage components", IEEE Trans. Ind. Appl., vol.IA-20, no.3, pp.625-630, 1984.

[5] H. Kawahira, T. Nakamura, S. Nakazawa, "Active power filters", IEEJ IPEC-Tokyo, pp.981-992, 1983.

[6] H. Akagi, A. Nabae, S. Atoh, "Control strategy of active power filters using multiple voltage-source PWM converters", IEEE Trans. Ind. Appl., vol.IA-22, no.3, pp.460-465, 1986.

[7] M. Takeda, K. Ikeda, Y. Tominaga, "Harmonic current compensation with active filter", IEEE/IAS, Annual Meeting, pp.808-815, 1987.

[8] H. Akagi, "Trends in active power line conditioners", IEEE/IES, IECON, pp.19-24, 1992.

[9] S. Moran, "A line voltage regulator/conditioner for harmonic-sensitive load isolation", IEEE/IAS, Annual Meeting, pp.947-951, 1989.

[10] F. Z. Peng, H. Akagi, A. Nabae, "A new approach to harmonic compensation in power systems - A combined system of shunt passive and Series Active Filters", IEEE/IAS, Annual Meeting, pp874-880, 1988.

[11] H. Fujita, H. Akagi, "A practical approach to harmonic compensation in power systems - Series connection of passive and active filters", IEEE/IAS, Annual Meeting, pp.1107-1112, 1990.

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