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The unified power quality conditioner: the integration of series and shunt-active filters

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The Unified Power Quality Conditioner: The Integration of Series Active Filters and Shunt Active Filters

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Abstract - This paper deals with the "unified power quality conditioners (UPQCs)," which aim at integration of series active filters and shunt active filters. The main purpose of a UPQC is to compensate for voltage flicker/imbalance, reactive power, negative sequence current, and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems.

This paper discusses control strategy of the UPQC, with the focus on the flow of instantaneous active and reactive power inside the UPQC. Some interesting experimental results obtained from a laboratory model of 20kVA, along with theoretical analysis, are shown to verify the viability and effectiveness of the UPQC.

I. INTRODUCTION

A specially designed twelve-pulse thyristor rectifier of 5–8MVA is required as a low voltage high current dc power supply for super-conductive material tests. The thyristor rectifier is, however, too susceptible to low frequency variation of the utility voltage, or to the so-called "voltage flicker" to generate a strong magnetic field with high stability. If large capacity arc furnaces or cycloconverters are connected to the same or upstream power system, the thyristor rectifier would suffer from voltage flicker at the utility-consumer point of common coupling.

This paper deals with the "unified power quality conditioners (UPQCs)" [1][2][3], which aim at integration of series active filters [4][5][6][7] and shunt active filters. The main purpose of a UPQC is to compensate for supply voltage flicker/imbalance, reactive power, negative-sequence current, and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC, therefore, is expected as one of the most powerful solutions to large capacity loads sensitive to voltage flicker/imbalance .

This paper presents two types of UPQCs: One is a general UPQC for power distribution systems and industrial power systems. The other is a specific UPQC for a voltage flicker/imbalance-sensitive load, which is installed on his own premises by an electric power consumer. In this paper, much attention is paid to the specific UPQC consisting of a series active filter and a shunt active filter. The series active filter eliminates voltage flicker/imbalance from the load terminal voltage, and forces an existing shunt passive filter to absorb all the current harmonics produced by a nonlinear load. Elimination of voltage flicker, however, is accompanied by low frequency fluctuation of active power flowing into or out of the series active filter. The shunt active filter performs dc link voltage regulation, thus leading to a significant reduction of capacity of the dc capacitor. This paper reveals the flow of instantaneous active and reactive power inside the UPQC, and shows some interesting experimental results obtained from a laboratory model of 20kVA.

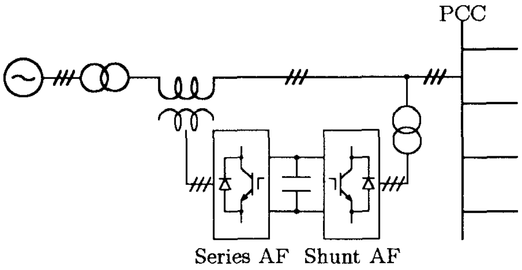

Figure 1: General unified power quality conditioner.

II. GENERAL UPQC

Fig.1 shows a basic system configuration of a general unified power quality conditioner consisting of the combination of a series active filter and a shunt active filter. The general UPQC will be installed at substations by electric power utilities in the near future. The main purpose of the series active filter is harmonic isolation between a subtransmission system and a distribution system. In addition, the series active filter has the capability of voltage flicker/imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer

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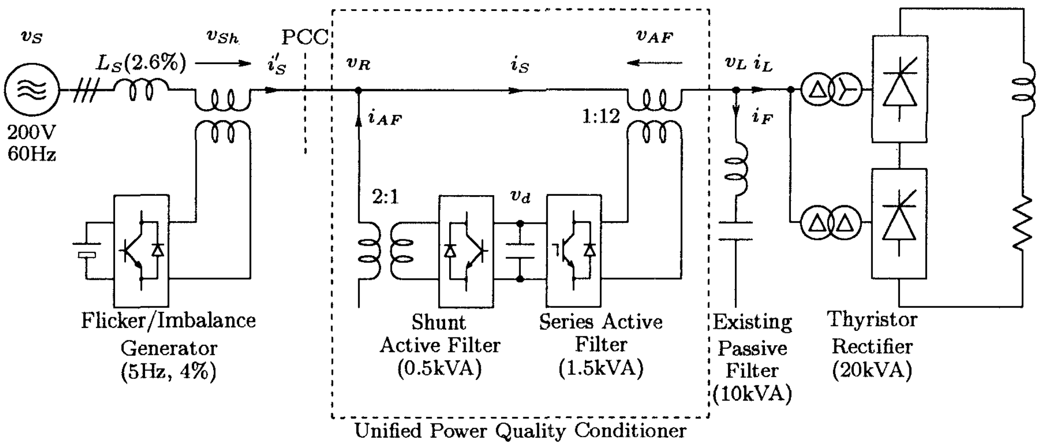

Figure 2: Specific unified power quality conditioner used in experiment.

Table 1: Circuit constants of existing shunt passive filter.

	L[mH]	C[μF]	Q	Capacity
5th	1.1	260	30	4kVA
7th	1.1	130	30	2kVA
HPF	0.19	260	—	4kVA

point of common coupling (PCC). The main purpose of the shunt active filter is to absorb current harmonics, to compensate for reactive power and negative-sequence current, and to regulate the dc link voltage between both active filters.

The integration of the series active filter and the shunt active filter is named the "unified power quality conditioner" in this paper, associated with the unified power flow controller which has been proposed by Gyugyi [8]. However, the unified power quality conditioner for distribution systems is quite different in purpose, operation, and control strategy from the unified power flow controller for transmission systems.

III. EXPERIMENTAL SYSTEM

Fig.2 shows an experimental system configuration of a specific unified power quality conditioner. The aim of the specific UPQC is not only to compensate for the current harmonics produced by a twelve-pulse thyristor rectifier of 20kVA, but also to eliminate the voltage flicker/imbalance contained in the receiving terminal voltage v_R from the load terminal voltage v_L. The receiving terminal in Fig.2 is often corresponding to the utility-consumer point of common coupling in high power applications. The UPQC consists of a 1.5kVA series active filter and a 0.5kVA shunt active filter. The dc links of both active filters are connected to a common dc capacitor of 2000μF. The twelve-pulse thyristor bridge rectifier is considered a voltage flicker/imbalance-sensitive load just like a dc power supply for super-conductive material tests.

The power circuit of the 1.5kVA series active filter consists of three single-phase voltage-fed PWM inverters using four IGBTs in each phase. The operation of the series active filter greatly forces all the current harmonics produced by the thyristor rectifier into an existing shunt passive filter of 10kVA. It has also the capability of damping series/parallel resonance between the supply impedance and the shunt passive filter.

The 0.5kVA shunt active filter consisting of a three-phase voltage-fed PWM inverter is connected in parallel to the supply by a step-up transformer. The only objective of the shunt active filter is to regulate the dc link voltage between both active filters. Although it has the capability of reactive power compensation, the shunt active filter in Fig.2 provides no reactive power compensation in order to achieve the minimum required rating of the shunt active filter. The shunt passive filter consists of 5th and 7th-tuned LC filters and a high-pass filter. The 10kVA shunt passive filter circuit constants are shown in Table 1.

There is a notable difference in the installation point of shunt active filter between Figs.1 and 2. The reason is clarified as follows: In Fig.1, the shunt active filter compensates for all the current harmonics produced by nonlinear loads downstream of the PCC. Therefore, it should be connected downstream of the series active filter acting as a high resistor for harmonic frequencies. In Fig.2, the shunt active filter draws or injects the active power fluctuating at a low frequency from or into the supply, while the existing shunt passive filter absorbs the current harmonics. To avoid interference between shunt active and passive filters, the shunt active filter should be connected upstream.

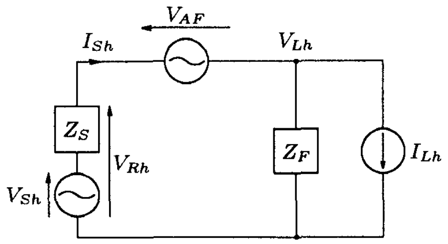

Figure 3: Equivalent circuit for harmonics.

A voltage-fed PWM inverter connected in series with the supply is used as a voltage flicker/imbalance generator in this experiment.

IV. COMPENSATION STRATEGY

Fig.3 shows a single-phase equivalent circuit for Fig.2. For the sake of simplicity, the shunt active filter is removed from Fig.3 because it has no effect on harmonic and flicker compensation. Three kinds of control methods are discussed as follows:

(a) current-detecting method

$$V_{AF}^* = K \cdot I_{Sh} \tag{1}$$

(b) voltage-detecting method

$$V_{AF}^* = V_{Rh} \tag{2}$$

(c) combined method

$$V_{AF}^* = K \cdot I_{Sh} + V_{Rh} \tag{3}$$

A. *Current-Detecting Method*

Fig.4 shows an equivalent circuit where the current-detecting method is applied. Equation (1) means that the series active filter acts as a resistor of $K[\Omega]$ for harmonics. The load terminal voltage harmonics V_{Lh} and the supply current harmonics I_{Sh} are given as follows.

$$V_{Lh} = \frac{Z_F}{Z_S + Z_F + K} V_{Sh} - \frac{Z_S + K}{Z_S + Z_F + K} Z_F I_{Lh} \tag{4}$$

$$I_{Sh} = \frac{1}{Z_S + Z_F + K} V_{Sh} + \frac{Z_F}{Z_S + Z_F + K} I_{Lh} \tag{5}$$

If the feedback gain K is set as $K \gg Z_S + Z_F$, neither voltage harmonics nor voltage flicker appears at the load terminal, irrespective of voltage harmonics and flicker existing at the receiving terminal. As a result, both the load terminal voltage and the supply current become purely sinusoidal. It is, however, difficult to set K much larger than $Z_S + Z_F$ for voltage flicker because Z_F exhibits high capacitive impedance at the fundamental frequency. Thus, the current-detecting method in (1) is not suitable for voltage flicker compensation.

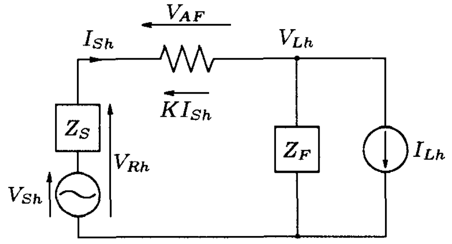

Figure 4: Equivalent circuit in case of current-detecting method.

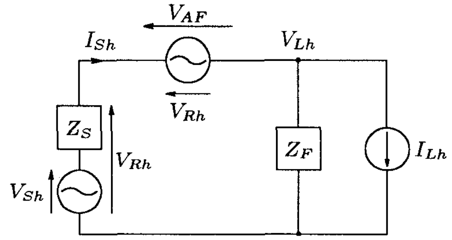

Figure 5: Equivalent circuit in case of voltage-detecting method.

B. *Voltage-Detecting Method*

Fig.5 shows an equivalent circuit based on the voltage-detecting method in (2). Because the output voltage of the series active filter V_{AF} cancels the receiving terminal voltage harmonics V_{Rh}, neither voltage harmonics nor voltage flicker appears at the load terminal, that is,

$$V_{Lh} = 0. \tag{6}$$

However, the existing shunt passive filter loses the capability of trapping current harmonics, so that all the current harmonics produced by the load escape to the supply, that is,

$$I_{Sh} = I_{Lh}. \tag{7}$$

Thus, the voltage-detecting method in (2) is not suitable for harmonic compensation of the load.

C. *Combined Method*

Fig.6 shows an equivalent circuit in case of combination of Figs.4 and 5. It is clear from (3) that the series active filter looks like a series connection of a voltage source V_{Rh} and a resistor $K[\Omega]$. The receiving terminal voltage harmonics V_{Rh} and supply current harmonics I_{Sh} are given by the following equations.

$$V_{Lh} = -\frac{KZ_F}{Z_F + K} I_{Lh} \tag{8}$$

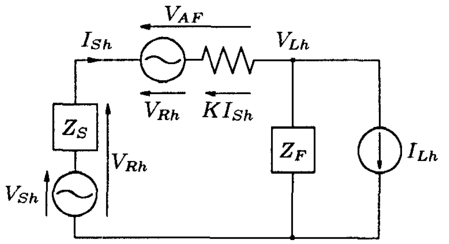

Figure 6: Equivalent circuit in case of combined method.

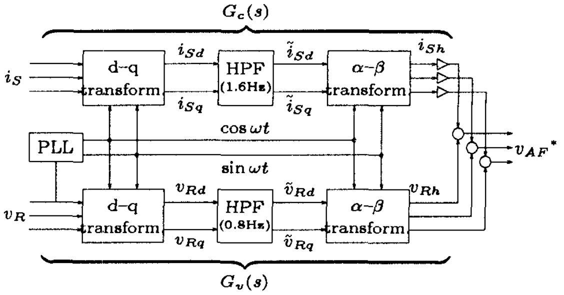

Figure 7: Control circuit of series active filter.

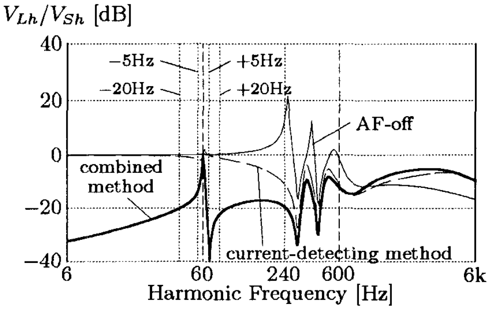

Figure 8: Compensation characteristics of V_{Lh}/V_{Sh}.

$$I_{Sh} = \frac{Z_F}{Z_F + K} I_{Lh} \tag{9}$$

If K is set larger than Z_F for harmonics, the combined method can eliminate the supply current harmonics I_{Sh} as well as the current-detecting method can. Note that the supply harmonic and/or flicker voltageV_{Sh} is excluded from (8). The first term on the right hand of (3) plays a role in harmonic current compensation of the load, while the second term contributes to voltage flicker cancellation of the supply. Assuming that K is infinite, the output voltage of the series active filter, V_{AF} is given by

$$\lim_{K \to \infty} V_{AF} = Z_F I_{Lh} + V_{Sh}. \tag{10}$$

V. COMPENSATING CHARACTERISTICS

A. *Control Circuit*

Fig.7 shows a control circuit of the series active filter based on the combined control method of (3). The control circuit consists of two $d-q$ transformation circuits $G_c(s)$ and $G_v(s)$ which take the detected supply current i_S and the detected receiving terminal voltage v_R, respectively.

Two first-order high-pass filters (HPFs) with the cut-off frequency of 1.6Hz in $G_c(s)$ are used for extraction of current harmonics i_{Sh}, while those with the cut-off frequency of 0.8Hz in $G_v(s)$ for extraction of voltage flicker/imbalance v_{Rh}. The control circuit is implemented in a DSP(TMS320C20).

B. *Analysis of compensating characteristics*

Fig.8 shows a ratio in voltage harmonics/flicker of the load terminal to the supply, which is given by

$$\left. \frac{V_{Lh}}{V_{Sh}} \right|_{I_{Lh}=0} = \frac{Z_F(1-G_v)}{(1-G_v)Z_S + Z_F + KG_c}. \tag{11}$$

When no series active filter is connected (AF-off), the supply harmonic voltage at 240Hz is amplified by about ten times at the load terminal because of series resonance between Z_S and Z_F. After the series active filter based on either the current-detecting method or the combined method is operated, no amplification occurs, that is, the ratio of V_{Lh} to V_{Sh} is less than 0dB in either case.

However, these two methods are quite different in voltage flicker-compensating characteristics. The plots for the current-detecting method are nearly 0dB in a frequency range of 60±20Hz because the current-detecting method has almost no capability of voltage flicker compensation in v_L. On the other hand, the plots for the combined method is $-15 \sim -20$dB for voltage flicker with a frequency range of $5 \sim 20$Hz. This means that the combined method has the capability of voltage flicker compensation of the supply.

Fig.9 shows a ratio of supply current harmonics with respect to load current harmonics.

$$\left. \frac{I_{Sh}}{I_{Lh}} \right|_{V_{Sh}=0} = \frac{Z_F}{(1-G_v)Z_S + Z_F + KG_c} \tag{12}$$

The plots for the current-detecting method are similar to those of the combined method. This means that the second term on the right hand of (3) makes no contribution to harmonic compensation.

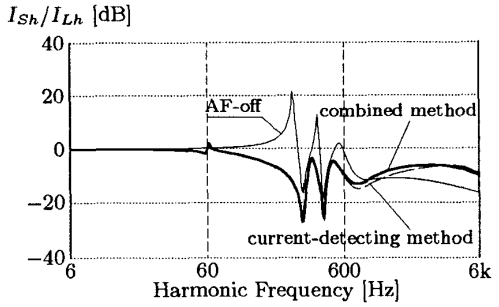

Figure 9: Compensation characteristics of I_{Sh}/I_{Lh}.

VI. FLOW OF INSTANTANEOUS ACTIVE AND REACTIVE POWER

A. *Instantaneous Active and Reactive Power in Series Active Filter*

Assuming that no shunt active filter is installed, the flow of instantaneous active and reactive power into or out of the series active filter is discussed with much emphasis on voltage flicker. Three-phase balanced voltages, v_{Sfu}, v_{Sfv} and v_{Sfw} are given by

$$\begin{bmatrix} v_{Sfu} \\ v_{Sfv} \\ v_{Sfw} \end{bmatrix} = \sqrt{2}V_{Sf} \begin{bmatrix} \cos\omega t \\ \cos(\omega t - 2\pi/3) \\ \cos(\omega t + 2\pi/3) \end{bmatrix}, \tag{13}$$

where

V_{Sf}: voltage amplitude
ω: supply angular frequency.

Because voltage flicker is considered a low frequency amplitude modulation of the fundamental supply voltage, voltage flicker $\Delta \boldsymbol{v}_S$ in each phase is given as follows:

$$\begin{bmatrix} \Delta v_{Su} \\ \Delta v_{Sv} \\ \Delta v_{Sw} \end{bmatrix} = \sqrt{2}\Delta v_S \begin{bmatrix} \cos\omega t \\ \cos(\omega t - 2\pi/3) \\ \cos(\omega t + 2\pi/3) \end{bmatrix}, \tag{14}$$

where

$\Delta v_S = \Delta V_S \cos(\omega' t + \phi')$,
ΔV_S: amplitude of voltage flicker,
ω': angular frequency of voltage flicker.

Hence, the supply voltage $\boldsymbol{v}_S$ is given as a sum of $\boldsymbol{v}_{Sf}$ and $\Delta \boldsymbol{v}_S$.

$$\begin{bmatrix} v_{Su} \\ v_{Sv} \\ v_{Sw} \end{bmatrix} = \begin{bmatrix} v_{Sfu} \\ v_{Sfv} \\ v_{Sfw} \end{bmatrix} + \begin{bmatrix} \Delta v_{Su} \\ \Delta v_{Sv} \\ \Delta v_{Sw} \end{bmatrix} \tag{15}$$

Because $\Delta \boldsymbol{v}_S$ is canceled by the series active filter, the load terminal voltage $\boldsymbol{v}_L$ equals $\boldsymbol{v}_{Sf}$, so that no voltage flicker appears at the load terminal. Therefore, the load current $\boldsymbol{i}_L$ has a constant amplitude of I_L and the passive filter current i_F have a constant amplitude of I_F.

With the series active filter operating, the passive filter is assumed to absorb all the load current harmonics. According to [9], instantaneous active power p_L ($p_F = 0$) and instantaneous reactive power $q_L + q_F$ on the upstream side of the load terminal are given by

$$\begin{aligned} \begin{bmatrix} p_L \\ q_L + q_F \end{bmatrix} &= \begin{bmatrix} v_{Sf\alpha} & v_{Sf\beta} \\ -v_{Sf\beta} & v_{Sf\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} + i_{F\alpha} \\ i_{L\beta} + i_{F\beta} \end{bmatrix} \\ &= 3V_{Sf} \begin{bmatrix} I_L \cos\phi \\ I_L \sin\phi + I_F \end{bmatrix}, \end{aligned} \tag{16}$$

where

$\cos\phi$: displacement power factor of load.

Taking into account the output voltage of the series active filter, $\Delta \boldsymbol{v}_S$, instantaneous active power p_{AF1} and instantaneous reactive power q_{AF1} inside the series active filter are obtained as follows:

$$\begin{aligned} \begin{bmatrix} p_{AF1} \\ q_{AF1} \end{bmatrix} &= \begin{bmatrix} \Delta v_{S\alpha} & \Delta v_{S\beta} \\ -\Delta v_{S\beta} & \Delta v_{S\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} + i_{F\alpha} \\ i_{L\beta} + i_{F\beta} \end{bmatrix} \\ &= 3\Delta v_S \begin{bmatrix} I_L \cos\phi \\ I_L \sin\phi + I_F \end{bmatrix}. \end{aligned} \tag{17}$$

The above equation means that p_{AF1} and q_{AF1} fluctuate at an angular frequency of ω'.

On the supply side, instantaneous active power p_S and instantaneous reactive power q_S are given by

$$\begin{aligned} \begin{bmatrix} p_S \\ q_S \end{bmatrix} &= \begin{bmatrix} v_{S\alpha} & v_{S\beta} \\ -v_{S\beta} & v_{S\alpha} \end{bmatrix} \begin{bmatrix} i_{S\alpha} \\ i_{S\beta} \end{bmatrix} \\ &= 3(V_{Sf} + \Delta v_S) \begin{bmatrix} I_L \cos\phi \\ I_L \sin\phi + I_F \end{bmatrix}. \end{aligned} \tag{18}$$

Equation (18) equals the sum of (16) and (17) as

$$\begin{bmatrix} p_S \\ q_S \end{bmatrix} = \begin{bmatrix} p_{AF1} \\ q_{AF1} \end{bmatrix} + \begin{bmatrix} p_L \\ q_L + q_F \end{bmatrix}. \tag{19}$$

Fig.10 shows the flow of instantaneous active and reactive power when no shunt active filter is connected. Note that p_L, q_L and q_F are constant values, while p_{AF1} and q_{AF1} fluctuate due to the supply voltage flicker of (14). The fluctuation of p_{AF1} results in the variation of the dc link voltage at ω' because no shunt active filter is connected. The total amount of instantaneous active power drawn from the supply also fluctuates at ω'. Note that q_{AF1} has no effect on the dc link voltage [9].

Assuming that the dc link voltage v_d is the sum of a fluctuating component $\tilde{v}_d$ and a constant component V_d, $\tilde{v}_d$ is given by

$$\tilde{v}_d = \frac{1}{C}\int \frac{p_{AF1}}{v_d}dt = \frac{1}{C}\int \frac{3\Delta v_S I_L \cos\phi}{v_d}dt. \tag{20}$$

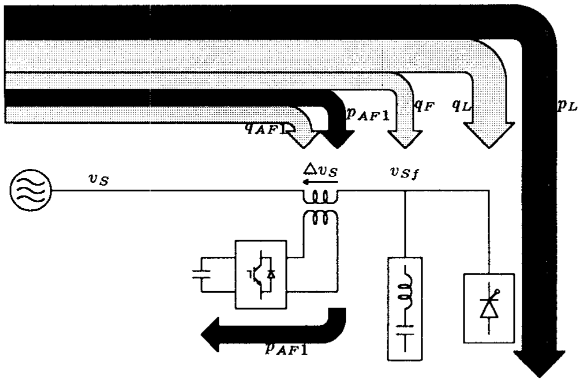

Figure 10: Flow of instantaneous active and reactive power when no shunt active filter is installed.

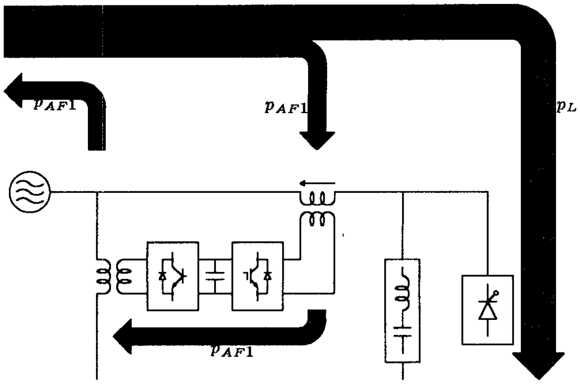

Figure 11: Flow of instantaneous active power when shunt active filter is operated.

The following approximation exists as long as the fluctuation of $\tilde{v_d}$ is much smaller than V_d.

$$\tilde{v_d} \fallingdotseq \frac{3\Delta V_S I_L \cos\phi}{\omega' C V_d} \sin(\omega' t + \phi') \tag{21}$$

The ratio of $\tilde{v_d}$ to V_d, ε is given by

$$\varepsilon = \frac{3\Delta V_S I_L \cos\phi}{\omega' C {V_d}^2}. \tag{22}$$

Note that ε is inversely proportional to flicker frequency. This means that a larger capacity of dc capacitor is required to compensate for voltage flicker fluctuating at a lower frequency.

B. *DC Link Voltage Regulation*

The purpose of the shunt active filter is to inject instantaneous active power p_{AF2} into the supply, and to keep instantaneous reactive power q_{AF2} to be zero. Here, p_{AF2} is equal to p_{AF1}, so that no variation occurs in the dc link voltage. Accordingly, p_{AF2} and q_{AF2} are given by

$$\begin{bmatrix} p_{AF2} \\ q_{AF2} \end{bmatrix} = \begin{bmatrix} p_{AF1} \\ 0 \end{bmatrix}. \tag{23}$$

Fig. 11 shows the flow of instantaneous active power when the shunt active filter is operated. The instantaneous active power drawn from the supply, p_S equals p_L because p_{AF2} and p_{AF1} cancel each other at the receiving terminal. Here, p_S and q_S are given by

$$\begin{aligned} \begin{bmatrix} p_S \\ q_S \end{bmatrix} &= \begin{bmatrix} p_L \\ q_L + q_F + q_{AF1} \end{bmatrix} \\ &= \begin{bmatrix} 3V_{Sf} I_L \cos\phi \\ 3(V_{Sf} + \Delta v_S)(I_L \sin\phi + I_F) \end{bmatrix}. \end{aligned} \tag{24}$$

Although voltage flicker Δv_S is superimposed on the supply voltage v_S, p_S is constant, while q_S is not constant because q_{AF1} fluctuates. On the supply side, instantaneous active current i_{Sp} and instantaneous reactive current i_{Sq} can be derived from (24)

$$\begin{bmatrix} i_{Spu} \\ i_{Spv} \\ i_{Spw} \end{bmatrix} = \frac{\sqrt{2} V_{Sf} I_L \cos\phi}{V_{Sf} + \Delta v_S} \begin{bmatrix} \cos\omega t \\ \cos(\omega t - \frac{2}{3}\pi) \\ \cos(\omega t + \frac{2}{3}\pi) \end{bmatrix}, \tag{25}$$

$$\begin{bmatrix} i_{Squ} \\ i_{Sqv} \\ i_{Sqw} \end{bmatrix} = \sqrt{2}(I_L \sin\phi + I_F) \begin{bmatrix} \sin\omega t \\ \sin(\omega t - \frac{2}{3}\pi) \\ \sin(\omega t + \frac{2}{3}\pi) \end{bmatrix}. \tag{26}$$

The amplitude of i_{Sp} varies although p_S is constant. Whereas the amplitude of i_{Sq} is constant because Δv_S is excluded from (26).

VII. EXPERIMENTAL RESULTS

Figs. 12~15 show experimental results obtained from Fig. 2, when the voltage flicker of 4%, which fluctuates at 5Hz, is superimposed on the supply by the voltage flicker/imbalance generator. Fig. 13 is close-up waveforms of v_R and v_L in Fig. 12. With the help of the series active filter, the amplitude variation in v_L is reduced to 1/10, compared to that in v_R. The rms voltage of the series active filter is 4.4V (3.8%) of the supply, which is equal to the rms voltage of the supply flicker. The rms current of i_L is 60A, and the displacement power factor of the load is $\cos\phi = 0.45$, hence the fluctuating active power flowing into the series active filter is given by

$$3 \times 4.4 \times 60 \times 0.45 = 360\text{W}.$$

The shunt active filter injects i_{AF} into the supply, the amplitude of which fluctuates due to the voltage flicker in v_S. The variation of the dc link voltage is suppressed

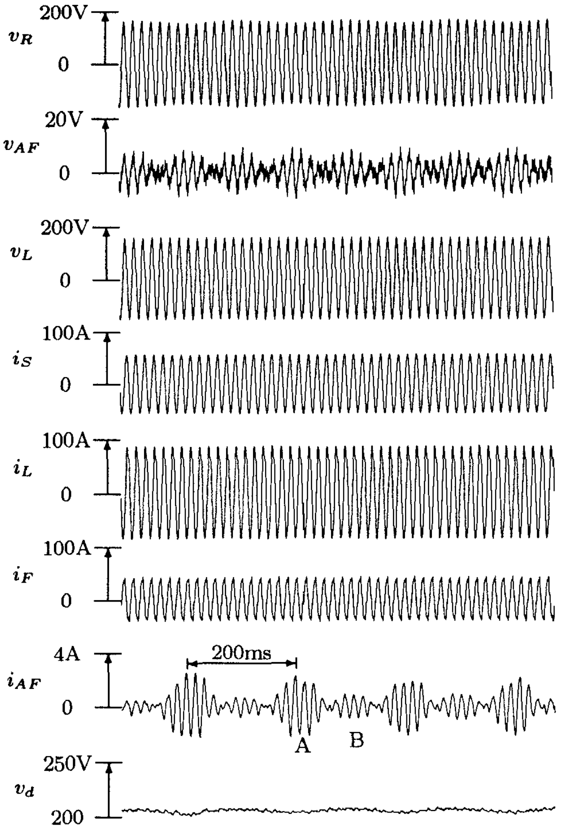

Figure 12: Experimental Waveforms.

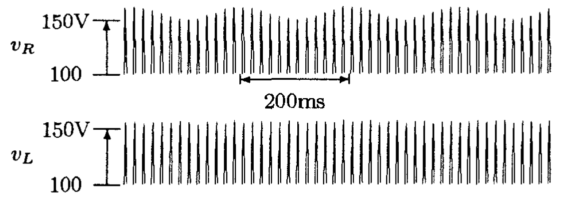

Figure 13: Close-up Waveform of v_R and v_L.

within only 2V (1%). This means that the shunt active filter returns almost all the active power drawn by the series active filter to the supply. If the shunt active filter is disconnected, the variation of the dc link voltage reaches

$$\varepsilon = \frac{3\Delta V_S I_L \cos\phi}{\omega' C V_d{}^2} = \frac{20 \times 10^3 \times 3.8/100 \times 1}{2\pi \times 5 \times 2000 \times 10^{-6} \times 200^2} = 13\%.$$

The active power of 520W flows into the shunt active filter at the point of A in Fig.12, while the active power of 170W flows out at the point of B. Thus, the variation of active power is (520 − 170)/2 = 345W. This is nearly equal to 360W.

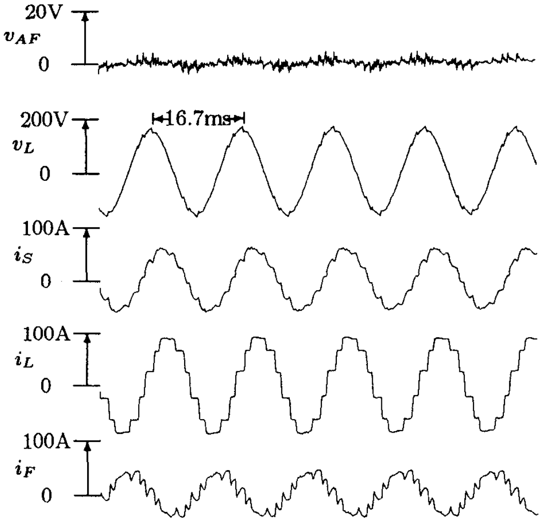

Figure 14: Experimental waveforms before both active filters are operated.

Figs.14 and 15 are experimental waveforms before and after starting the series active filter. The supply current i_S in Fig.14 includes a non-negligible amount of 11th and 13th harmonic currents. On the other hand, i_S in Fig.15 is a purely sinusoidal waveform.

Figs.16 and 17 show experimental waveforms under an imbalance condition with a negative-sequence voltage of 4% superimposed on the supply voltage by the voltage flicker/imbalance generator. Here, an induction motor of 2.2kW is connected to the UPQC as a load, which presents a low impedance at the negative-sequence. Before starting the series active filter, the three-phase load currents include a negative-sequence current of 1A. After started, the negative-sequence currents becomes 0.2A because the negative sequence in the load terminal voltage is reduced from 4% to less than 1%.

VIII. CONCLUSION

This paper has dealt with the "unified power quality conditioners," the aim of which is not only to compensate for current harmonics produced by nonlinear loads but also to eliminate voltage flicker/imbalance appearing at the receiving terminal from the load terminal. Theoretical comparison among three types of control methods has clarified that the combination of current and voltage-detecting methods is suitable for voltage flicker/imbalance elimination and harmonic compensation. The flow of instantaneous active and reactive power has shown that installa-

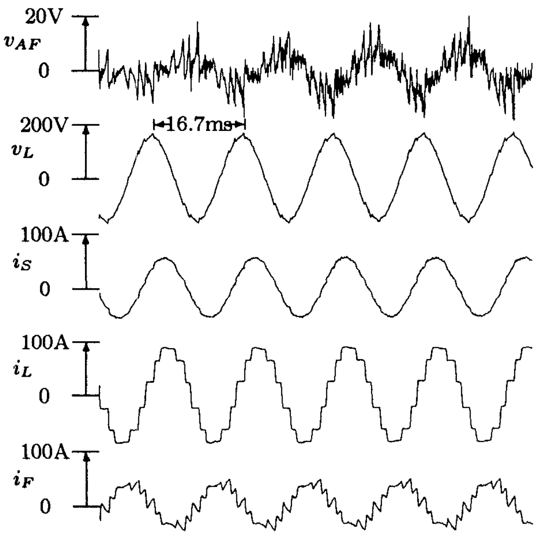

Figure 15: Experimental waveforms after both active filter are operated.

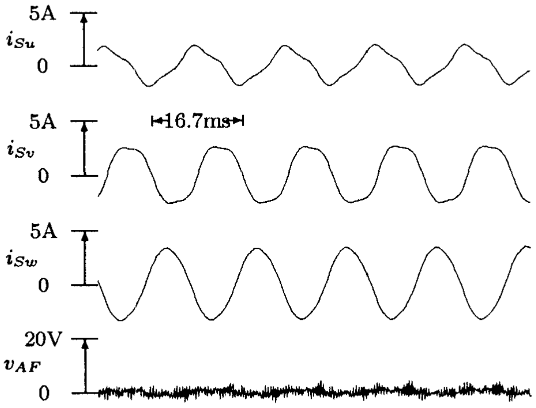

Figure 16: Experimental waveforms under voltage imbalance condition before starting series active filter.

tion of the shunt active filter is effective in eliminating a low frequency flicker of voltage.

Although the specific UPQC dealt with in this paper provides no power factor correction in order to minimize the required rating of the shunt active filter, the general UPQC is capable of improving "power quality" as well as improving power factor.

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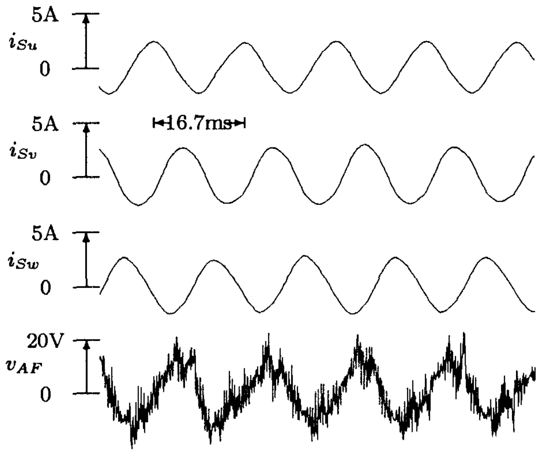

Figure 17: Experimental waveforms under voltage imbalance condition after starting series active filter.

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