Direct Power Control of PWM Converter Without Power-Source Voltage Sensors

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Abstract— **This paper proposes a novel control strategy of a pulewidth modulation (PWM) converter with no power-source voltage sensors. The strategy has two main features to improve a total power factor and efficiency, taking harmonic components into account without detecting the voltage waveforms. One feature is a direct instantaneous power control technique for the converter, which has been developed to control the instantaneous active and reactive power directly by selecting the optimum switching state of the converter. The other feature is an estimation technique of the power-source voltages, which can be performed by calculating the active and reactive power for each switching state of the converter from the line currents. A digital-signal-processor-based experimental system was developed, and experimental tests were conducted to examine the controllability. As a result, it was confirmed that the total power factor and efficiency were more than 97% and 93% over the load power range from 200 to 1400 W, respectively. These results have proven the excellent performance of the proposed system.**

Index Terms— **Direct power control, hysteresis comparator, instantaneous active power, instantaneous reactive power, pulsewidth modulation converter, switching table, total power factor, voltage sensorless operation.**

I. Introduction

As POWER electronic systems are extensively used, not only in industrial fields, but also in consumer products, several problems with regard to their diode rectifiers, which are employed mainly in the dc power supplies, have arisen in recent years. One of the problems is a low input power factor, and another problem is caused by harmonics in the input currents. Therefore, pulsewidth modulation (PWM) converters are adopted in applications that require less distortion in the current waveforms for the purpose of observing the strict regulations on electrical harmonics pollution. Since the converters have abilities to control the currents in sinusoidal waveforms, the unity power factor operation can be easily performed by regulating the currents in phase with the power-source voltages [1].

Paper IPCSD 98–13, presented at the 1996 Industry Applications Society Annual Meeting, San Diego, CA, October 6–10, and approved for publication in the IEEE Transactions on Industry Applications by the Industrial Power Converter Committee of the IEEE Industry Applications Society. Manuscript released for publication February 9, 1998.

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Publisher Item Identifier S 0093-9994(98)03880-8.

A conventional control technique for the PWM converter is based on the input current control, in which the current commands are provided from the detected power-source voltages [2]. The current controller normally employs a subharmonic or space vector PWM method, so that the sinusoidal current waveforms can be obtained for the purpose of improving the power factor. In general, the converter requires three kinds of sensors as follows:

1) ac current sensors for input current control (Hall-effect CT's);
2) a dc-bus voltage sensor for regulating the dc-bus voltage (an isolation amplifier);
3) ac voltage sensors for obtaining the current phase references (transformers or photo couplers).

The first and the second sensors are absolutely indispensable regarding not only system control, but also system protection, because overcurrent protection of the input lines and overvoltage protection in the dc bus are vital issues for the converter. The third sensors, however, can be omitted from the converter and should be eliminated from the viewpoint of simple implementation. In the case of a large-capacity converter, when the converter is installed in the plant, it is desirable to omit on-site adjustment of the voltage sensors and several feedback signal lines between the sensors and the controller. Also, elimination of the sensors can contribute to improving the system reliability against electrical noises to the lines, accidental cutting of the lines, and so forth.

This paper proposes a novel control technique of the PWM converter, which makes it possible to achieve the unity power factor operation by directly controlling its instantaneous active and reactive power without any voltage sensors. The technique has two unique features. One is a direct instantaneous power control technique of the converter, and the other is an estimation technique of the power-source voltage waveforms. The former is based on relay control of the instantaneous active and reactive power, and the converter has no current controller, although the conventional one has [4]. The relay control can be performed by selecting an optimum switching state of the converter, so that the active and reactive power errors can be restricted in appropriate hysteresis bands, which is possible by using a switching table and several hysteresis comparators. The latter is based on a calculation of the voltages for each switching state of the converter by detecting the line currents, and the calculation is performed by utilizing the active and reactive power as intermediate variables. Since this method deals with instantaneous variables in obtaining the voltages, it is possible to estimate not only a fundamental component [5],

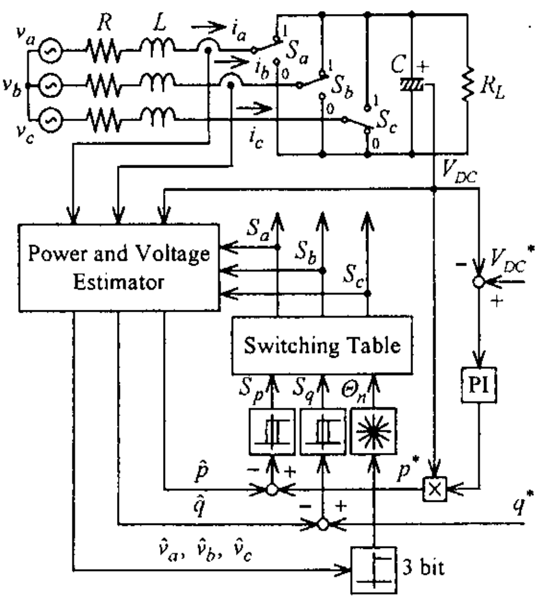

Fig. 1. Configuration of direct instantaneous active and reactive power controller for PWM converter.

but also harmonic components of the voltage waveforms. This feature also contributes to improve the total power factor and efficiency. In this paper, theoretical analysis and experimental results of the above system are presented, and feasibility of the proposed technique is verified.

II. Principles of Direct Power Control Without Power-Source Voltage Sensors

A. Direct Power Control of PWM Converter

Fig. 1 shows the configuration of the direct instantaneous active and reactive power controller for the PWM converter in which the symbols are as follows:

- v_a, v_b, v_c three-phase power-source voltages;
- i_a, i_b, i_c three-phase line currents;
- S_a, S_b, S_c switching states of the converter;
- V_{DC} dc-bus voltage;
- L inductance of interconnecting reactors;
- R resistance of interconnecting reactors;
- C smoothing capacitor across the dc bus;
- R_L load resistance.

Hereafter, it is assumed that the value of R is negligibly small and the switching devices in the converter are functionally ideal, i.e., they require no lockout function and have no forward voltage drops.

The controller features relay control of the active and reactive power by using hysteresis comparators and a switching table. In this configuration, the dc-bus voltage is regulated by controlling the active power, and the unity power factor operation is achieved by controlling the reactive power to be zero. As shown in Fig. 1, the active power command p^* is provided from a dc-bus voltage control block, while the reactive power command q^* is directly given from the outside of the controller. Errors between the commands and the estimated feedback power are input to the hysteresis

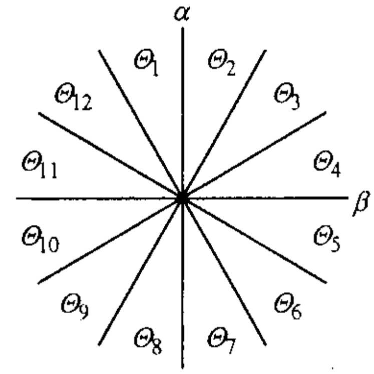

Fig. 2. Twelve sectors on stationary coordinates to specify voltage vector phase.

TABLE I
Switching Table for Direct Instantaneous Power Control

Sp	Sq	Θ1	Θ2	Θ3	Θ4	Θ5	Θ6	Θ7	Θ8	Θ9	Θ10	Θ11	Θ12
1	0	101	111	100	000	110	111	010	000	011	111	001	000
	1	111	111	000	000	111	111	000	000	111	111	000	000
0	0	101	100	100	110	110	010	010	011	011	001	001	101
	1	100	110	110	010	010	011	011	001	001	101	101	100

comparators and digitized to the signals S_p and S_q. Also, the phase of the power-source voltage vector is converted to the digitized signal θ_n. For this purpose, the stationary coordinates are divided into 12 sectors, as shown in Fig. 2, and the sectors can be numerically expressed as

$$(n-2)\frac{\pi}{6} \le \theta_n < (n-1)\frac{\pi}{6} \quad \because n = 1, 2, \cdots, 12. \tag{1}$$

By using several comparators, it is possible to specify the sector where the voltage vector exists.

The digitized error signals S_p and S_q and digitized voltage phase θ_n are input to the switching table in which every switching state, S_a, S_b, and S_c, of the converter is stored, as shown in Table I. By using this switching table, the optimum switching state of the converter can be selected uniquely in every specific moment according to the combination of the digitized input signals. The selection of the optimum switching state is performed so that the power errors can be restricted within the hysteresis bands.

B. Power-Source Voltage Estimation

The instantaneous apparent power s can be expressed in several different manners as

$$\begin{aligned} \boldsymbol{s} &= \boldsymbol{v}\bar{\boldsymbol{i}} = p + jq \\ &= v_a i_a + v_b i_b + v_c i_c + j\frac{1}{\sqrt{3}}[(v_b - v_c)i_a \\ &\quad + (v_c - v_a)i_b + (v_a - v_b)i_c] \end{aligned} \tag{2}$$

where

- $\boldsymbol{v}$ instantaneous power source voltage vector;
- $\boldsymbol{i}$ instantaneous line current vector;
- $\bar{\boldsymbol{x}}$ complex conjugate of a vector $\boldsymbol{x}$;
- j imaginary unit.

It is known that the calculation of the active power p is a scalar product between the voltages and the currents, whereas the reactive power q can be calculated by a vector product between them.

It is naturally possible to estimate the power-source voltages by simply adding converter output voltages to the voltage drops in the interconnecting reactors. However, variations of the neutral point of the converter have to be considered in calculating the power-source voltages, because the neutral point potential of the power source is not generally given. In order to avoid such an intricate procedure for calculation of the neutral point potential, the proposed method utilizes p and q information as intermediate variables in estimating the power-source voltages. Also, the estimated p and q can be used effectively as power feedback signals in the direct power controller described previously. However, (2) requires the power-source voltage information, which has to be eliminated to achieve the voltage sensorless operation. Rewriting p and q with the switching state of the converter, the three-phase line currents, the dc-bus voltage, and the inductance of the reactors, estimated values $\hat{p}$ and $\hat{q}$ can be derived as

$$\hat{p} = \hat{L}\left(\frac{di_a}{dt}i_a + \frac{di_b}{dt}i_b + \frac{di_c}{dt}i_c\right) + V_{DC}(S_a i_a + S_b i_b + S_c i_c) \quad (3)$$

$$\hat{q} = \frac{1}{\sqrt{3}}\left\{3\hat{L}\left(\frac{di_a}{dt}i_c - \frac{di_c}{dt}i_a\right) - V_{DC}[S_a(i_b - i_c) + S_b(i_c - i_a) + S_c(i_a - i_b)]\right\}. \quad (4)$$

As can be seen in (3) and (4), the estimating equations have to be changed according to the switching state of the converter, and both equations require the parameter $\hat{L}$ of the reactors. In a strict sense, the parameter $\hat{R}$ also has to be considered in estimating the active power, but it can be practically neglected because the power dissipated in the resistance is much lower than the active power associated with the dc bus and the inductance of the reactors.

Supposing practical data processing of the above equations by using microprocessors or digital signal processors (DSP's), differential operations of the currents are performed on the basis of calculus of finite differences. Therefore, it is necessary to suppress steep current ripples due to the converter switching by employing a relatively large inductance and to calculate the finite differences of the currents as accurately as possible. In order to prevent the noises and to improve the accuracy of the differential operation, the calculation of the finite differences should be carried out about ten times during the switching period and should be avoided at the very moment of the switching.

After estimating $\hat{\boldsymbol{s}} = \hat{p} + j\hat{q}$ by (3) and (4), the power source voltage vector $\hat{\boldsymbol{v}}$ can be estimated by

$$\hat{\boldsymbol{v}} = \frac{\boldsymbol{i}}{|\boldsymbol{i}|^2}\hat{\boldsymbol{s}} \quad (5)$$

where

$|\boldsymbol{x}|$ magnitude of a vector $\boldsymbol{x}$.

TABLE II
ELECTRICAL PARAMETERS OF POWER CIRCUIT

Resistance of reactors R	0.2 [Ω]
Inductance of reactors L	11.5 [mH]
Smoothing capacitor C	4700 [μF]
Load resistance R_L	100 [Ω]
Averaged switching frequency f_{sw}	8 [kHz]
Power source voltage V	200 [V]
Power source frequency f	50 [Hz]
DC bus voltage command V_{DC}^*	283 [V]

Generally, the amplitude of the current vector is not zero, because the dc bus of the converter is loaded by R_L; hence, (5) can be solved with respect to $\hat{\boldsymbol{v}}$. The above equation is rewritten in concrete forms by using the three phase variables as follows:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (6a)$$

$$\begin{bmatrix} \hat{v}_\alpha \\ \hat{v}_\beta \end{bmatrix} = \frac{1}{i_\alpha^2 + i_\beta^2}\begin{bmatrix} i_\alpha & -i_\beta \\ i_\beta & i_\alpha \end{bmatrix}\begin{bmatrix} \hat{p} \\ \hat{q} \end{bmatrix} \quad (6b)$$

$$\begin{bmatrix} \hat{v}_a \\ \hat{v}_b \\ \hat{v}_c \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} \hat{v}_\alpha \\ \hat{v}_\beta \end{bmatrix}. \quad (6c)$$

Since the proposed estimation method has been derived throughout by using instantaneous variables, it is possible to estimate harmonic components of the power-source voltages, as well as the fundamental components. This implies that improvement of the total power factor and efficiency taking the harmonics into account can be expected by this method.

III. EXPERIMENTAL SYSTEM AND RESULTS

A. Experimental System Configuration

An experimental prototype has been developed to examine operating characteristics of the proposed technique. The power circuit of the PWM converter is constituted by an insulated gate bipolar transistor (IGBT)-based full-bridge circuit. the electrical parameters of which are shown in Table II. Two Hall-effect CT's and an isolation amplifier are employed to detect the line currents and the dc-bus voltage, respectively. Mostly, the control circuits consist of digital hardware, although the hysteresis comparators for relay control of the power and their peripheral circuits are constituted by analog hardware. The estimation of the instantaneous power and the voltages is proceeded by a DSP (TMS320C50-40MHz), and the estimation program is executed in every 9-μs control period which is regularly initiated by an internal timer of the DSP. It is essential to make the control period as short as possible, because the estimating equations have to be changed every time the switching state of the converter is changed, as described by (3) and (4). The interface circuits which deal with detection of the line currents are specially designed to attain a fast data acquisition corresponding to the control period of the DSP. For this purpose, high-sampling-rate and high-resolution analog-to-digital converters (ADC's) (ADS-231-12bit-1.5MS/s) are employed in the system. The use of

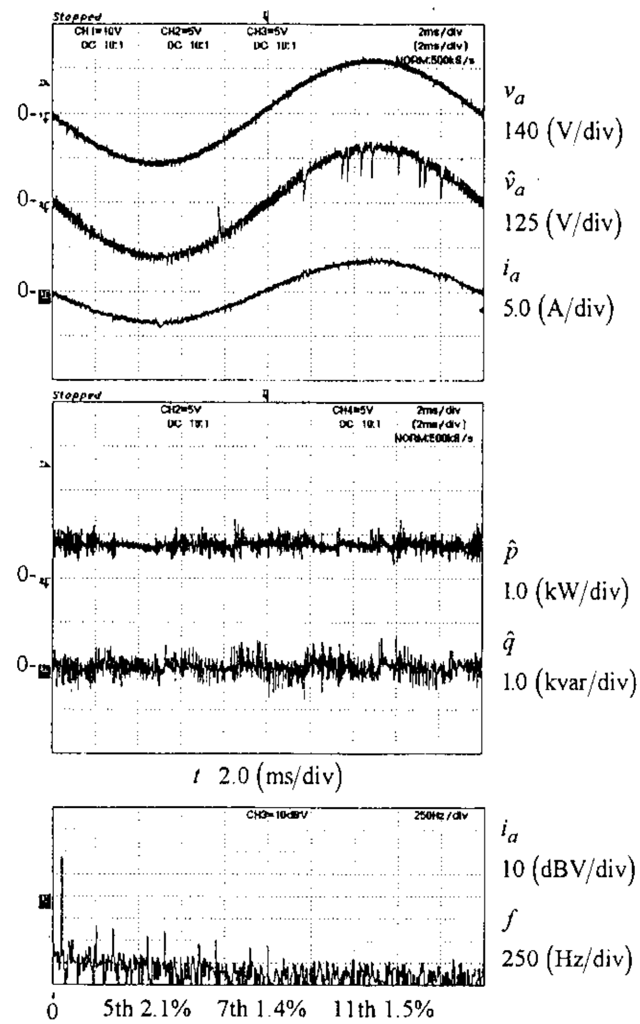

Fig. 3. Waveforms under unity power factor operation in steady state.

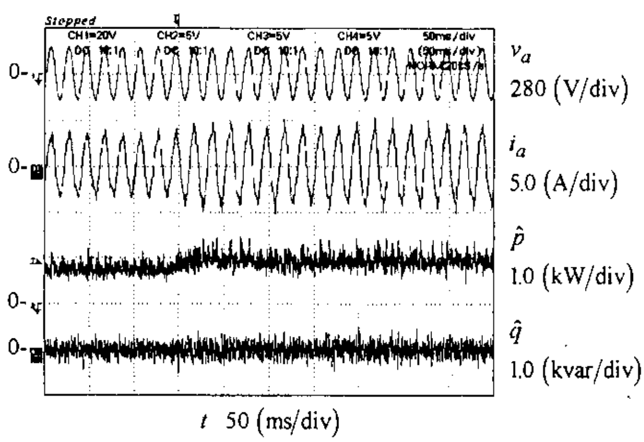

Fig. 4. Step response with respect to disturbance load power under unity power factor operation.

the DSP and the ADC's might be an economic drawback, but their costs can be negligible in larger capacity converters.

B. Experimental Results and Analysis

Several experimental tests were conducted to verify feasibility of the proposed technique. Fig. 3 shows an experimental result under the unity power factor operation in the steady

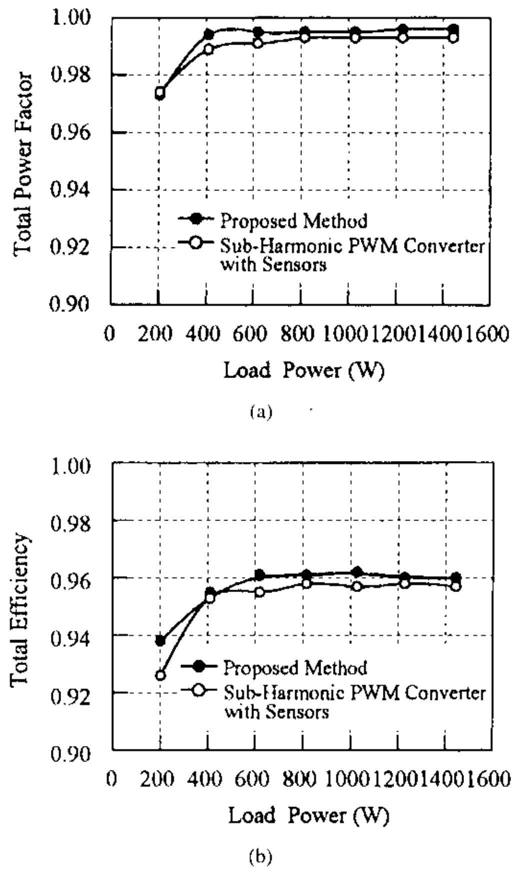

Fig. 5. Total power factor and efficiency. (a) Total power factor. (b) Total efficiency.

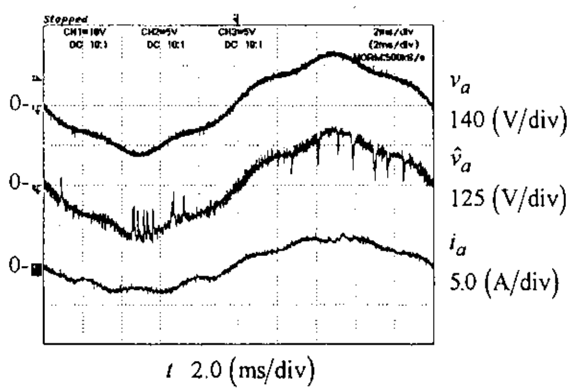

Fig. 6. Waveforms under unity power factor operation when the fifth harmonic is superposed on power-source voltages.

state. Power dissipated in the load resistance was 810 W. From this figure, it can be seen that the power-source voltage is successfully estimated and that the line current is in phase with the actual power-source voltage because the reactive power is controlled to be zero. The current waveform slightly contains lower order harmonic distortion, but this is because the feedback signals to the power controller are provided intermittently from the DSP at the interval of the control period. Therefore, it is considered that the discrete-time-system-based errors have caused such a distortion in the waveform. As shown in the oscillogram in the middle of Fig. 3, the estimated active power indicates almost the same value as the load power, and the

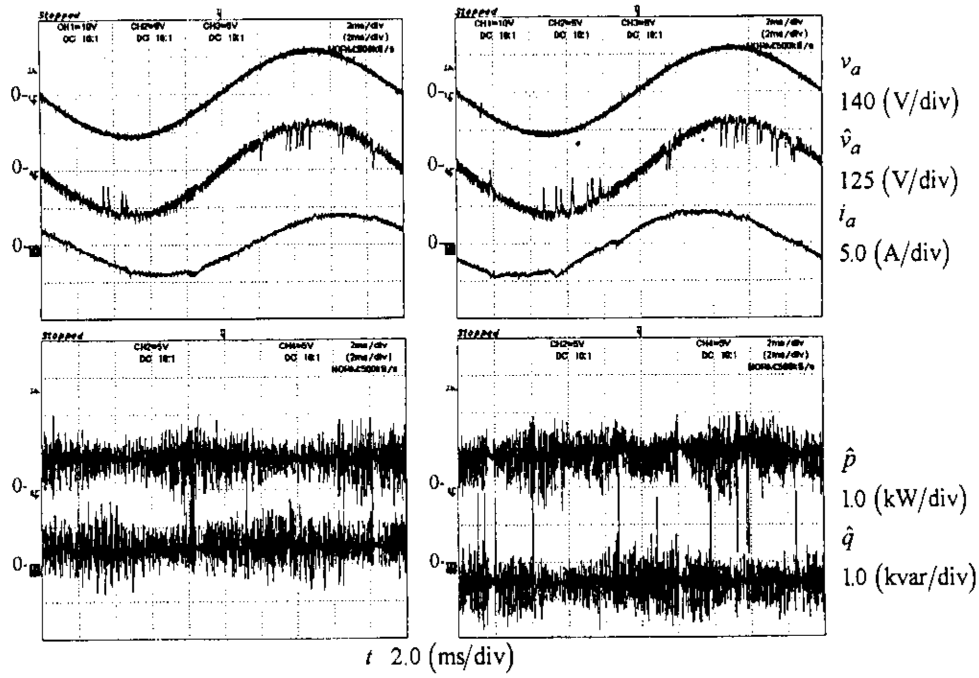

Fig. 7. Waveforms under lagging and leading power factor operation. (a) Lagging power factor operation; $q^* = +500$ var. (b) Leading power factor operation; $q^* = -500$ var.

estimated reactive power is zero on average because of the unity power factor operation. The fast Fourier transform (FFT) analysis result shows frequency spectra of the line current, and the fifth, the seventh, and the eleventh harmonic components can be identified in the bottom of Fig. 3. The current waveform distortion brings increase of the lower order harmonics as described above, but the higher order harmonic components are barely visible, as shown in the frequency spectra.

Fig. 4 shows a result of a step response against the disturbance load power under the unity power factor operation. The load power was changed stepwise from 750 to 900 W in this experiment. It can be observed that the estimation of the power and voltages can be performed and that the unity power factor operation is successfully achieved, even in this transient state. From Fig. 4, it can be found that the active power control and the reactive power control are independent of each other.

Fig. 5 shows several plots of the total power factor and efficiency of the converter, and the characteristics of the conventional system with a subharmonic PWM current controller are also shown in the figure for comparison. According to Fig. 5(a), the maximum power factor of the proposed system is more than 99% in the heavy-load region, while the power factor degrades to 97% as the load power decreases to 200 W. It is considered that the lower harmonics detrimentally affect the characteristic in the light-load condition. It can be seen that the proposed method is superior to the conventional one by approximately 0.5% in the total power factor. On the other hand, Fig. 5(b) shows the efficiency characteristic of the two methods. The proposed method demonstrates the maximum efficiency of 96% and more than 93% even in the light-load condition. It can be seen that the proposed method is barely superior to the conventional one in the total efficiency, also.

Fig. 6 shows waveforms in which the fifth harmonic component of 10% was intentionally superposed on the power-source voltage. It is observed that the proposed method can estimate the distorted voltage waveform accurately. In order to improve the total power factor, as well as the displacement factor, the line current should be controlled so that its waveform may be similar to that of the voltage, as shown in Fig. 6.

The proposed method can control the power factor indirectly by changing the reactive power command. Fig. 7 shows examples of the operating characteristics under lagging and leading power factor operations. In these experiments, the reactive power command has been changed to +500 var or −500 var, and it is confirmed that the controller can adjust the current phase indirectly with respect to the voltage through the reactive power command.

As described in (3)–(5), the proposed method requires the inductance $\hat{L}$ value to estimate the active and reactive power, and the source voltages. Therefore, it is necessary to examine the influence of the parameter mismatch on the operating characteristics of the converter. Fig. 8 shows the experimental results of the unity power factor operation when ±20% parameter mismatch is in the $\hat{L}$ of the controller. According to Fig. 8(a), if the value of the controller has +20% error from the actual one, the parameter mismatch detrimentally affects the estimated voltage waveform, as well as the active and reactive power waveforms. However, current waveform does not have very serious degradation, and the characteristic of the unity power factor operation still holds good. To the contrary, if the parameter mismatch of −20% is in the $\hat{L}$, it can be seen from Fig. 8(b) that the mismatch hardly affects the operating waveforms and the unity power factor operation. Since the parameter $\hat{L}$ has a close relation

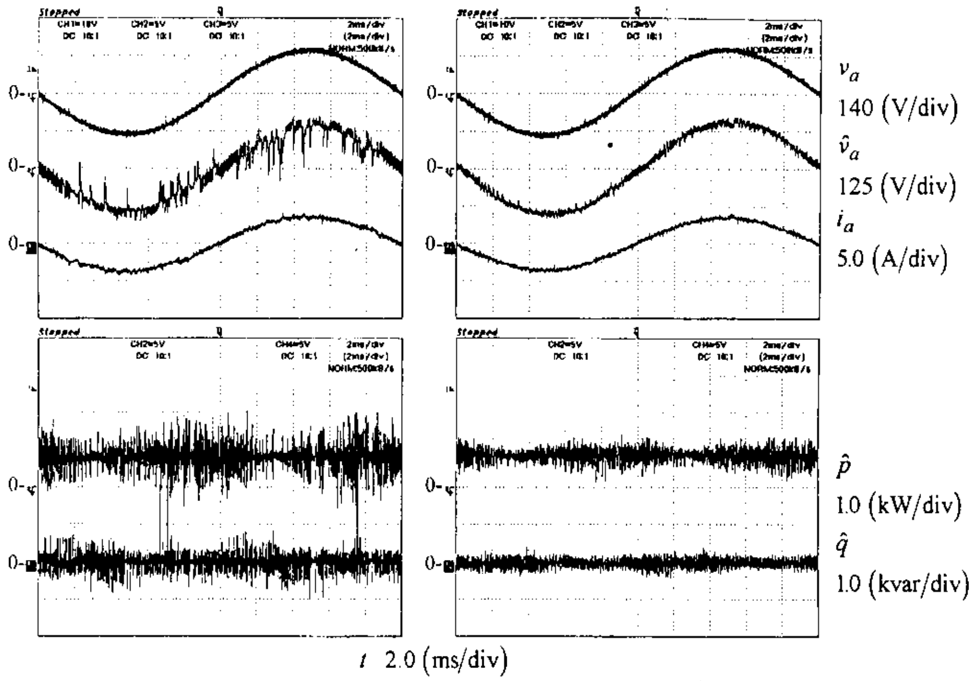

Fig. 8. Waveforms in the case of parameter mismatch in inductance. (a) +20% error. (b) −20% error.

to the differential operations of the currents, as described in (3) and (4), its mismatch mainly affects switching ripples of the estimated waveforms. Fig. 9 shows the influence of the inductance mismatch on the power control. This characteristic has been obtained through computer simulation tests, and averaged active and reactive power errors are plotted against the parameter error ratio $(\hat{L} - L)/L \times 100\%$. If a specific error ratio is taken up, for example, ±20%, the reactive power error caused by the positive mismatch $(\hat{L} > L)$ is less than that of the negative mismatch $(\hat{L} < L)$, which means that the positive mismatch has less influence on the power factor control. Furthermore, even though the active power error is caused by the inductance mismatch, it can be compensated for by the dc-bus voltage control loop. Therefore, the situation of the negative mismatch should be avoided in setting the inductance value of the controller.

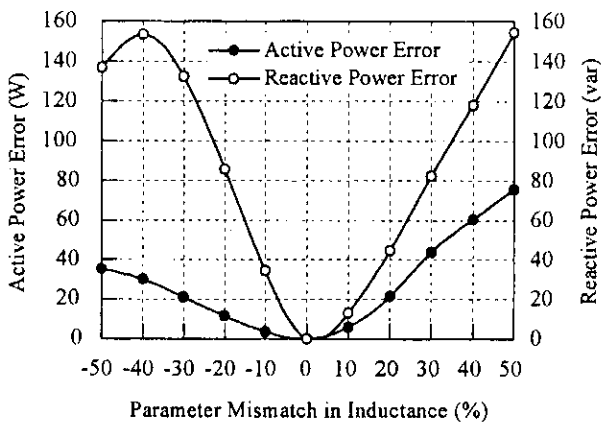

Fig. 9. Influence of inductance mismatch on power control.

IV. Conclusion

This paper has described two novel concepts to improve the total power factor and efficiency of the PWM converter without power-source voltage sensors. The first key point of the method is direct instantaneous active and reactive power control of the converter, and the second one is an estimation technique of the voltages for sensorless operation. The active and reactive power can be regulated directly by relay control of the power, which is implemented by using several comparators and a switching table. In this configuration, the errors between the power commands and the feedback signals are compared by the hysteresis elements, and the specific switching state of the converter is appropriately selected by the switching table, so that the errors can be restricted within the hysteresis bands. The voltage estimation method is based on an evaluation of the instantaneous active and reactive power for every switching state of the converter, which can be used as the feedback signals to the power controller. This method enables one to estimate the instantaneous values of the voltages, i.e., the fundamental component and the harmonic components of the voltages; hence, it is possible to improve the total power factor and efficiency without any voltage sensors by combining with the direct power control. The experimental results of a prototype have proven that the maximum total power factor was 99% and the maximum efficiency was 96%. Also, the total power factor and efficiency were more than 97% and 93%, even in the light-load condition, respectively. These results have shown that the proposed technique makes it possible to control the voltage sensorless PWM converter without sacrificing the operating performance.

REFERENCES

[1] T. Kataoka, K. Mizumachi, and S. Miyairi, "A pulsewidth controlled ac-to-dc converter to improve power factor and waveform of ac line current," *IEEE Trans. Ind. Applicat.*, vol. 15, pp. 670–675, Nov./Dec. 1979.

[2] R. Wu, S. B. Dewan, and G. R. Slemon, "Analysis of a PWM ac to dc voltage source converter under the predicted current control with a fixed switching frequency," *IEEE Trans. Ind. Applicat.*, vol. 27, pp. 756–764, July/Aug. 1991.

[3] J. W. Dixon and B.-T. Ooi, "Indirect current control of a unity power factor sinusoidal current boost type three-phase rectifier," *IEEE Trans. Ind. Electron.*, vol. 35, pp. 508–515, Aug. 1988.

[4] T. Takeshita, T. Kobayashi, and N. Matsui, "A scheme of power source voltage sensorless three-phase PWM AC/DC converter," *Trans. Inst. Elect. Eng. Jpn. Ind. Applicat.*, vol. 114, no. 12, pp. 1211–1219, 1994.

[5] T. Noguchi, H. Tomiki, S. Kondo, I. Takahashi, and J. Katsumara, "Instantaneous active and reactive power control of PWM converter by using switching table," *Trans. Inst. Elect. Eng. Jpn. Ind. Applicat.*, vol. 116, no. 2, pp. 222–223, 1996.

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