The Effect of Asynchronous Carrier on Matrix Converter Characteristics

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ABSTRACT – In a matrix converter, input side and output side are coupled with each other through switching elements. Since disturbances on either side affect directly on the other side, it requires a high-speed on-line control system to compensate them.

We proposed in previous papers a new control strategy and an on-line control circuit for a matrix converter. The control circuit could keep the output voltage at commanded value against fluctuation in the supply voltage. Furthermore wave forms of the output voltage and the input current were always kept sinusoidal. The switching pattern was generated by comparing modified voltage references with a carrier. The carrier was synchronized with the supply voltage using a PLL system, which made the control circuit complicated and costly.

This paper discusses on the possibility of an asynchronized carrier. Experiment results show the input current distortion in case of asynchronous carrier is bigger than that of synchronous carrier. However, the deterioration can be minimized by increased carrier frequency.

1. INTRODUCTION

In a matrix converter, input side and output side are coupled with each other through switching elements. Since disturbances on either side, such as fluctuation in power supply voltage and sudden change in load current, affect directly on the other side, it requires a high-speed on-line control system to compensate them.

We proposed in previous papers[1]-[4] a new control strategy and built a prototype matrix converter with a proposed on-line control circuit. The proposed on-line control circuit could generate the maximum output voltage of 0.866 times supply voltage and kept the output voltage constant and sinusoidal against fluctuation, asymmetry or harmonics in the supply voltage. The control circuit also realized the sinusoidal wave form in the input current as well as the output voltage.

The switching pattern of the matrix converter was generated by comparing modified voltage references with a carrier. The carrier was synchronized with the supply voltage using a PLL system, which made the control circuit complicated and costly.

In this paper, we discusses on the possibility of an asynchronized carrier experimentally.

2. CONTROL STRATEGY

The circuit diagram of the matrix converter is illustrated in Fig. 1. $S_{au}, S_{av}, \dots, S_{cw}$ are bi-directional switches. Inductors L and condensers C are for filtering the carrier frequency components.

Fig. 2 shows three-phase supply voltages e_u, e_v, e_w and input current references i_u^*, i_v^*, i_w^*. The current references are set to be symmetric and sinusoidal. θ is phase displacement angle of the input current.

Now we define e_{max}, e_{mid}, e_{min}, i_{max}^*, i_{mid}^* and i_{min}^* as follows.

$e_{max} = \mathrm{MAX}[e_u, e_v, e_w]$,
$e_{mid} = \mathrm{MID}[e_u, e_v, e_w]$,
$e_{min} = \mathrm{MIN}[e_u, e_v, e_w]$,
$i_{max}^* = \mathrm{MAX}[i_u^*, i_v^*, i_w^*]$,
$i_{mid}^* = \mathrm{MID}[i_u^*, i_v^*, i_w^*]$,
$i_{min}^* = \mathrm{MIN}[i_u^*, i_v^*, i_w^*]$

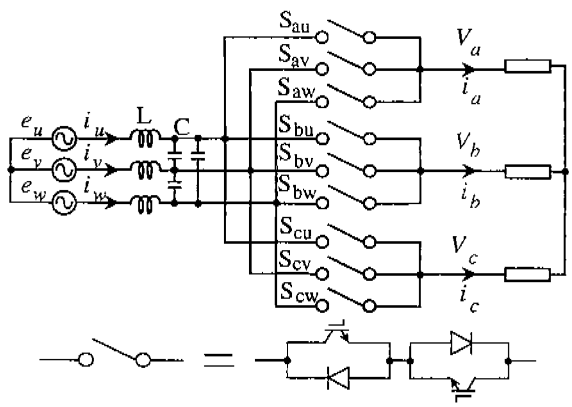


Fig. 1 Circuit diagram.

e_{imax}, e_{imid}, e_{imin} are defined as the supply phase voltages of the i_{max}*, i_{mid}*, i_{min}* respectively. The base voltage is changed according to the polarity of the intermediate input current reference i_{mid}* as shown in Fig. 2. Polarity of i_{mid}* is plus in region X and minus in region Y.

The control method at $\theta=0$ is illustrated in Fig. 3. In the region X, the output phase with the lowest output command is connected to the base voltage e_{min} and the output phase with the highest output command is connected to the base voltage e_{max} in region Y. It is required that $e_{max}=e_{imax}$ and $e_{min}=e_{imin}$, i.e. $-\pi/6\leq\theta\leq\pi/6$. Other two output phases are connected to e_{imax}, e_{imid} or e_{imin} according to V_{SX}* in region X or V_{SY}* in region Y. V_{SX}* and V_{SY}* ($S=a,b,c$) are output line voltage commands based on the lowest and highest output phase voltage command shown in Fig. 4.

Fig. 5 shows how to make the switching pattern in region X. T_0, T_1 are determined to satisfy the following equations.

$$\{(T_2-T_1)\Delta e_{max}+(T_1-T_0)\Delta e_{mid}\}/T_2 = V_{SX}^* \quad (1)$$

$$(T_1-T_0)/(T_2-T_1) = C_2/C_1 = a \quad (2)$$

where, T_2: one half period of the carrier,

$\Delta e_{max} = e_{imax} - e_{min}$, $\Delta e_{mid} = e_{imid} - e_{min}$.

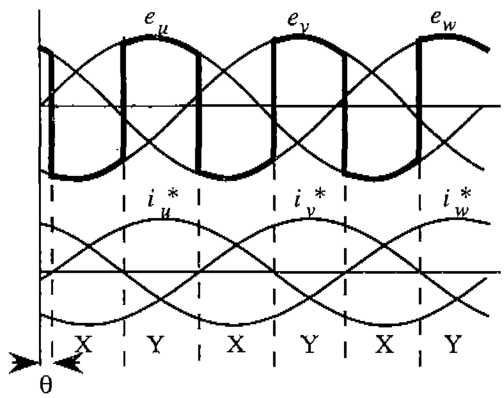


Fig. 2 Pulse Timing.

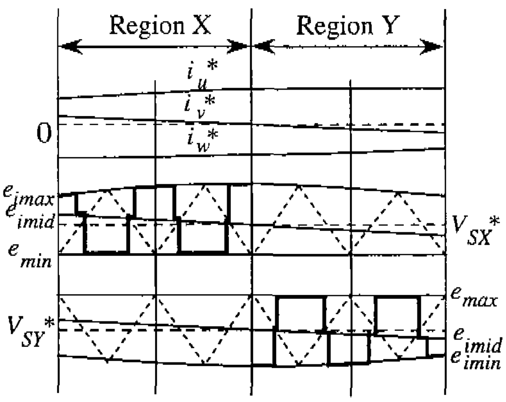


Fig. 3 The principle of control method.

The supply voltages, output commands and output currents are assumed to be constant during T_2. Equation (1) means the average of output voltage is defined equal to the average of output voltage command in T_2.

Equation (2) is to equate the ratio of input currents in two phases, i_{mid}* and i_{max}*, to the ratio of the two input current references. C_2 and C_1 are area of i_{mid}* and i_{max}*, respectively, as shown in Fig. 5. We call a the distribution factor of currents.

Equation (3) and (4) are obtained from (1) and (2).

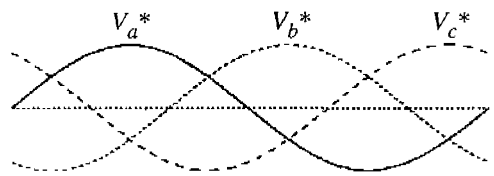
$$T_0 / T_2 = 1 - (1+a)V_{SX}^* / \{\Delta e_{max}+a\Delta e_{mid}\} \quad (3)$$

$$T_1 / T_2 = 1 - V_{SX}^* / \{\Delta e_{max} + a\Delta e_{mid}\} \quad (4)$$

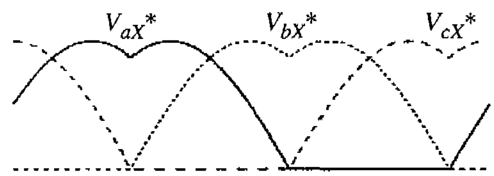
Fig. 6 is illustrated by use of equations (3) and (4). The T_0 and T_1 can be determined by comparing the command $(1+a)V_{SX}$* and V_{SX}* with the triangular wave whose amplitude is modulated by the $\Delta e_{max}+a\Delta e_{mid}$.

The switching pattern in region Y is similarly made by using V_{SY}*. It can be proved that the output voltage of 0.866 times the supply voltage can be obtained by this control method if input displacement factor is set to be unity.

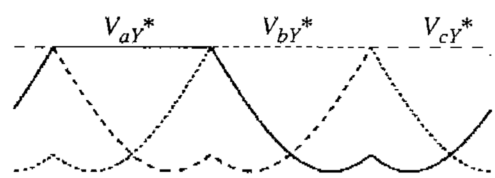
Under on-line control, a is read from controller with the instantaneous angle of input current reference which is the instantaneous angle of supply phase voltage plus θ. It should be noticed that on-line control can be simply realized without high speed CPU.



(a) The output phase voltage command.



(b) The output line voltage command in region X.



(c) The output line voltage command in region Y.

Fig. 4 The output voltage commands.

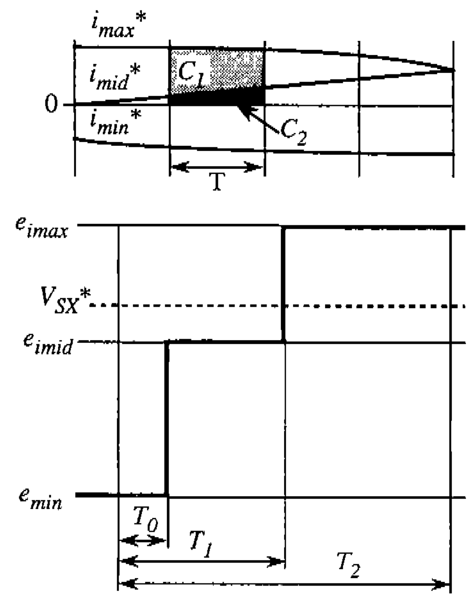


Fig. 5 Switching pattern.

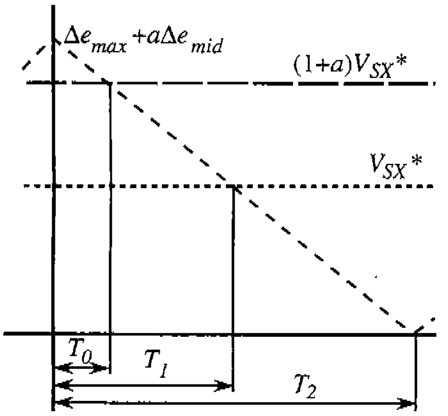


Fig. 6 Pulse timing.

3. SYSTEM CONFIGURATION

The system configuration of our matrix converter is shown in Fig. 7. Back-to-back connected 600 V, 100 A IGBTs with a parallel diode are used as the switching elements, and two 16-bit microprocessors are used for the controller. The distribution factor a is uniquely decided from the pre-calculated input current wave form command.

In our experiments, the input current wave form reference is a three phase symmetrical sine wave synchronized with the supply frequency (unity power factor). The values a, V_{SX}* and V_{SY}* are outputted by the CPU using tables at interrupt signals synchronized with the supply voltage, and then converted to analog wave form using D/A converters. These signals are input to the gate pulse generator, together with Δe_{max} and Δe_{min} extracted from the power supply. The H & L signals, which are output from the gate pulse generator and then input to the gate logic circuit, determine the connecting periods to e_{max}, e_{mid} and e_{min}. The gate logic circuit generates gate pulses of appropriate firing sequence according to the polarity of supply voltage, which prevents voltage/current spikes.

4. EXPERIMENTAL RESULTS

T_0 and T_1 can be determined by comparing modified line voltages with the triangular carrier wave as shown in Fig. 6. The triangular wave should be synchronized with the supply voltage wave form for better performance. But if the asynchronized triangular wave is allowed, the control system becomes much simpler.

From Fig. 8 to 11 compare the experimental results with synchronized triangular wave and asynchronized triangular wave. The load is resistive. Inductance and capacitance of the filter are L=0.6mH and C=20μF. The input voltage is 80V, output voltage command is 66V, and frequency command is 30 Hz. The carrier frequency of the triangular waves are 1,800 Hz in Fig. (a) and 4,680 Hz in Fig. (b), respectively.

Fig. 8 shows the output current - input power factor characteristics. Fig. 9 shows the efficiency characteristics. The distortion factor of input line voltage is shown in Fig. 10 and the distortion factor of the input current is in Fig. 11.

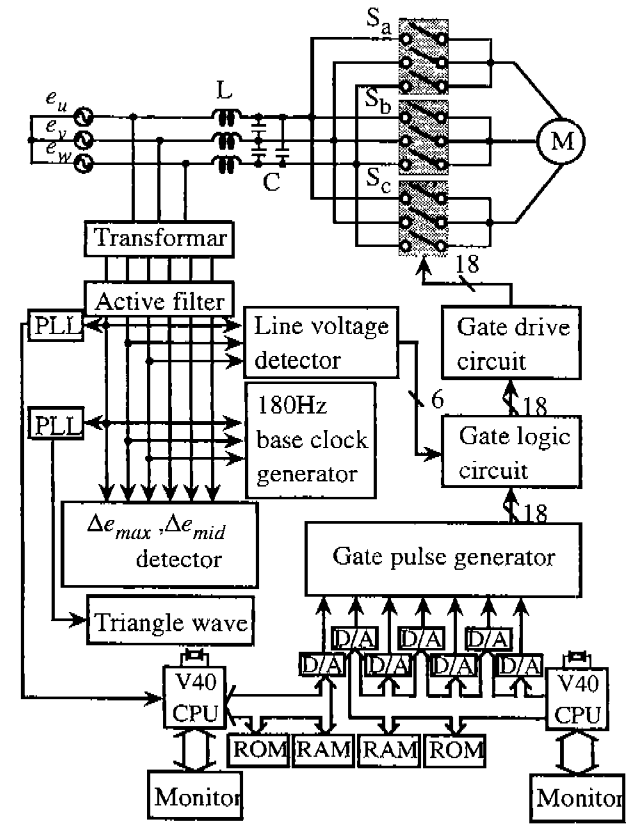


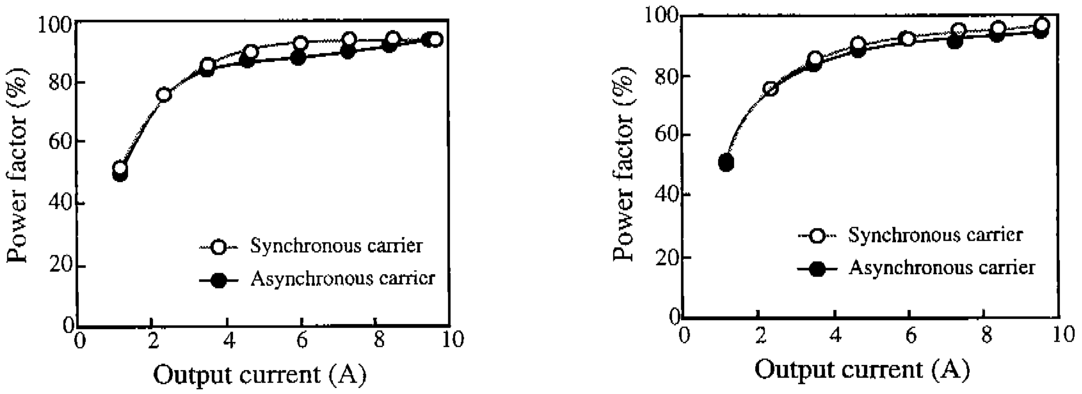
Fig. 7 System configuration.

Under the control with asynchronized triangular wave the power factor is lower and the distortion factor of input current is larger than under synchronized wave, as expected.

However, deterioration of performances under asynchronized triangular wave at 4,680 Hz of the carrier frequency is much less than at 1,800 Hz. The wave forms of the input voltage, input current, output voltage and output current are shown in Fig. 12. It is shown that the wave forms under asynchronous carrier with 4,680Hz is very smooth.

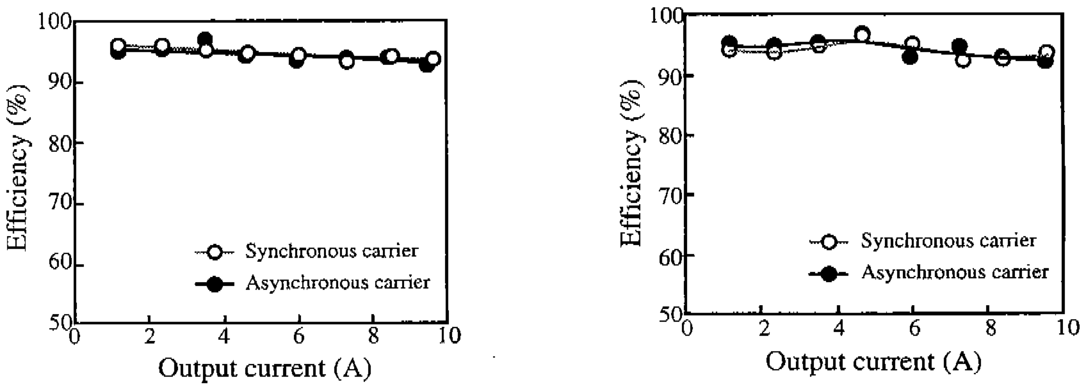
5. CONCLUSION

The effect of asynchronous carrier of the matrix converter on the performance characteristics is studied experimentally. It is shown that the input current distortion with the asynchronous carrier is bigger than that with the synchronous carrier. However the deterioration shall be minimized by increasing the carrier frequency.



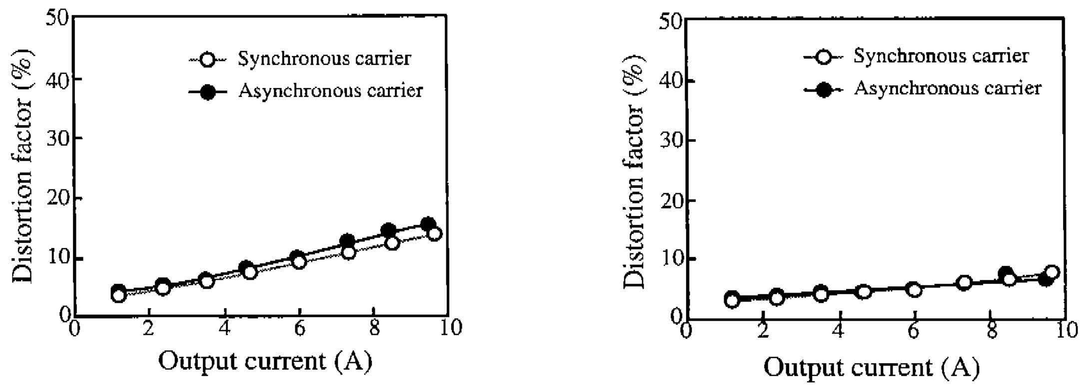
(a) f_c = 1,800 Hz (b) f_c = 4,680 Hz

Fig. 8 Characteristics of power factor.



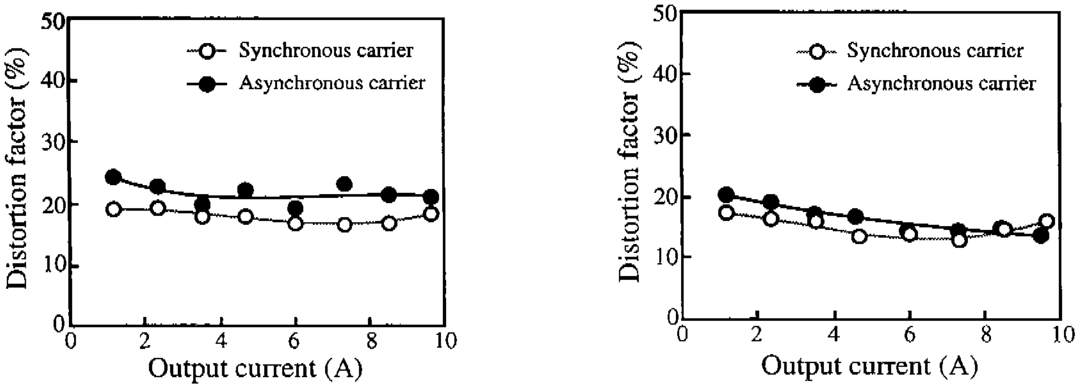
(a) f_c = 1,800 Hz (b) f_c = 4,680 Hz

Fig. 9 Characteristics of efficiency.



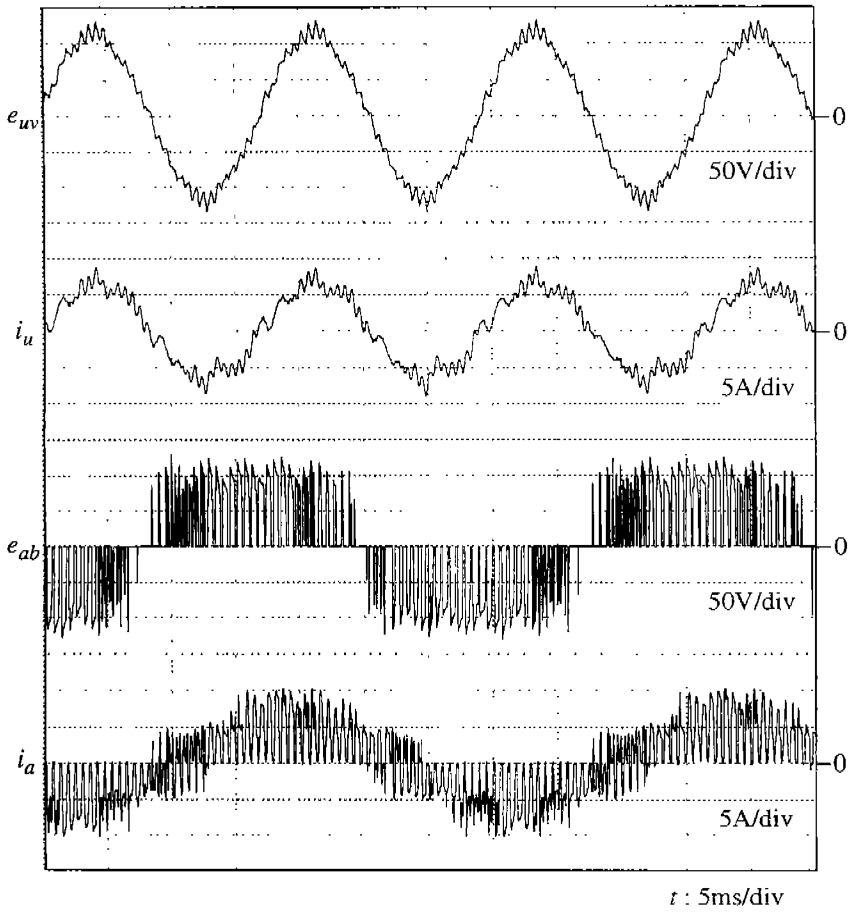
(a) f_c = 1,800 Hz (b) f_c = 4,680 Hz

Fig. 10 Distortion factor of input line voltage.

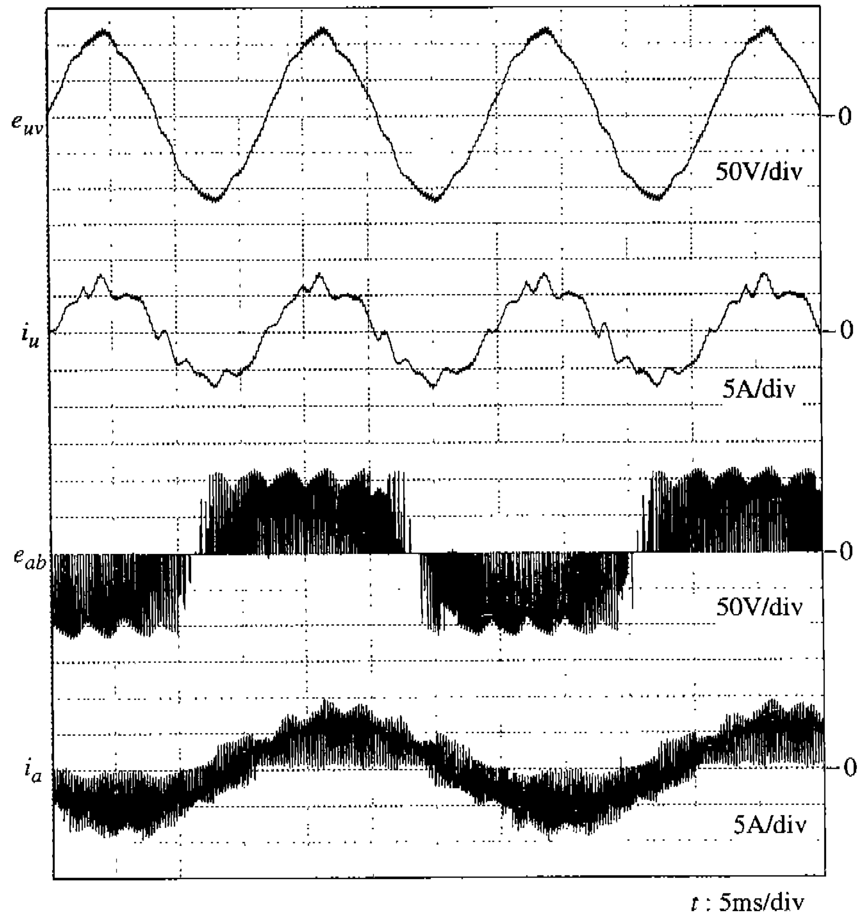


(a) f_c = 1,800 Hz (b) f_c = 4,680 Hz

Fig. 11 Distortion factor of input current.



(a) f_c = 1,800 Hz



(b) f_c = 4,680 Hz

Fig. 12 Experimental waveforms under asynchronous carrier.

6.REFERENCES

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