

MATRIX CONVERTER AND  
CONTROL METHOD FOR THE MATRIX CONVERTER

TECHNICAL FIELD

5     [0001]     The present invention relates to a matrix  
converter and a control method for the matrix converter.  
More specifically, the invention relates to a matrix  
converter and a matrix converter control method for  
converting a three-phase ac input voltage into a specified  
10 three-phase ac output voltage.

BACKGROUND ART

[0002]     As a typical main circuit construction for  
inverters, indirect ac power conversion circuits for  
15 converting a commercial alternating current into a direct  
current via a rectifier circuit and a smoothing circuit to  
obtain an ac output by a voltage-type converter are  
generally used. Meanwhile, as a method for obtaining an ac  
output directly from an ac voltage, direct ac power  
20 converter apparatuses typified by matrix converters are  
known. In this case, since large capacitors and reactors  
for smoothing voltage pulsations by commercial frequencies  
are unnecessary, converter miniaturization can be expected  
and therefore the direct ac power converter apparatuses

have been increasingly gaining attentions as next-generation power converter apparatuses.

[0003] A three-phase to three-phase matrix converter is to obtain ac output voltages of variable voltages and  
5 variable frequencies by direct switching of a three-phase ac input voltage. As a typical modulation method, an analog base modulation method in which, with a virtual DC link formed, sinusoidal modulation is performed by carrier comparison is proposed in Document 1 (Jun OYAMA and other  
10 five, "VVVF On-Line Control of PWM Cycloconverter", IEEJ Transactions D, IEEJ, Vol. 116 (1996), No. 6, pp. 664-651). Also, a control method for solving current distortion, which is an issue in asynchronism between output voltage command signal and carrier signal, is disclosed in Document  
15 2 (JP 11-341807 A).

[0004] The control methods of Documents 1 and 2, in either case, is based on an amplitude modulation which is accomplished by introducing a variable that is a current distribution ratio, i.e. a ratio of a mid phase current to  
20 a maximum phase current, and by multiplying a factor on each of an output voltage command signal and a carrier signal. Further, the control method of Document 2 involves two steps of control for suppressing changeover of switching patterns, which serve as information updating  
25 part, so that current distortion in carrier asynchronism is

avoided. Due to this, matrix converters of Documents 1 and 2 have an issue that control configuration and computation become more complex.

5 SUMMARY OF THE INVENTION

[0005] Embodiments of the present invention provide a matrix converter, as well as a matrix converter control method, which allows the control-related circuit construction to be simplified without involving such  
10 computations as ripple computation or carrier amplitude modulation.

[0006] According to the first aspect of the present invention, there is provided a matrix converter for converting a three-phase ac input voltage into a specified  
15 three-phase ac output voltage, comprising:

an output voltage command signal generating section for generating an output voltage command signal to output the specified three-phase ac output voltage;

a current flow ratio generating section for  
20 generating a signal representing a current flow ratio based on a specified input current command signal;

a signal correcting section for correcting the output voltage command signal based on the output voltage command signal generated by the output voltage command  
25 signal generating section and the signal representing the

current flow ratio generated by the current flow ratio  
generating section;

a PWM conversion signal generating section for  
generating a PWM conversion signal based on the output  
5 voltage command signal corrected by the signal correcting  
section and a carrier signal; and

a conversion section for converting the three-  
phase ac input voltage into the specified three-phase ac  
output voltage based on the PWM conversion signal generated  
10 by the PWM conversion signal generating section, wherein

given the input current command signals are  
represented by  $i_r^*$  ,  $i_s^*$  ,  $i_t^*$  and a voltage command is  
represented by  $V_s^*$  , assuming the lowest voltage phase as a  
reference voltage when a polarity of a mid phase out of the  
15 output voltage command signal is positive or the highest  
voltage phase as a reference voltage when the polarity of  
the mid phase out of the output voltage command signal is  
negative, the current flow ratio generating section  
generates the current flow ratio of the maximum phase by

$$V_s^* \frac{2}{\sqrt{3}} \max(|i_r^*|, |i_s^*|, |i_t^*|)$$

20 and generates a sum of the current flow ratio of the maximum  
phase and the current flow ratio of the mid phase by

$$V_s^* \frac{2}{\sqrt{3}} \max(|i_r^*|, |i_s^*|, |i_t^*|).$$

[0007] According to this matrix converter, based on the output voltage command signal generated by the output voltage command signal generating section and the signal representing the current flow ratio generated by the current flow ratio generating section, the output voltage command signal is corrected by the signal correcting section. Based on the corrected output voltage command signal and the carrier signal, the PWM conversion signal is generated by the PWM conversion signal generating section.

5

10 With such a modulation method by input current flow ratio, a constant average virtual dc link voltage can be obtained and, as a result, the control-related circuit construction can be simplified without involving such computations as ripple computation or carrier amplitude modulation.

[0009] Also, according to this matrix converter, the current flow ratio of the maximum phase as well as the sum of the current flow ratio of the maximum phase and the current flow ratio of the mid phase are generated by the current flow ratio generating section based on the input current command signal, and the output voltage command signal is corrected by using the current flow ratios. Thus, the virtual dc link voltage can be maintained as a constant dc voltage.

10 [0010] In one embodiment, given that the input current command signals are represented by  $i_r^*$ ,  $i_s^*$ ,  $i_t^*$  and that a phase angle of the input current command signals  $i_r^*$ ,  $i_s^*$ ,  $i_t^*$  relative to the output voltage command signal is

represented by  $\phi$ , the current flow ratio generating section generates the current flow ratio of the maximum phase by

$$\begin{aligned}\frac{2}{\sqrt{3}}\text{mid}(|i_r^*|, |i_s^*|, |i_t^*|) &= \frac{2}{\sqrt{3}}\sin(\pi/3 - \phi) \quad (\text{where } \pi/6 > \phi \geq 0) \\ &= \frac{2}{\sqrt{3}}\sin\phi \quad (\text{where } \pi/3 > \phi \geq \pi/6)\end{aligned}$$

and generates a sum of the current flow ratio of the maximum phase and the current flow ratio of the mid phase by

$$\frac{2}{\sqrt{3}}\max(|i_r^*|, |i_s^*|, |i_t^*|) = \frac{2}{\sqrt{3}}(\sin\phi + \sin(\pi/3 - \phi)).$$

5    **[0011]**    In this embodiment, in generating a current flow ratio based on the input current command signal, the current flow ratio generating section looks up to a single sine table, allowing further simplification to be achieved.

10    **[0012]**    In one embodiment, the carrier signal is a triangle wave signal having a generally constant amplitude.

15    **[0013]**    In this embodiment, the matrix converter is easily applicable to digital counters and comparators by virtue of its constant carrier amplitude, and suitable for digital control systems by virtue of its capability of maintaining the PWM modulation resolution constant. Moreover, the matrix converter, in which the triangle wave signal suitable for PWM modulation is used as the carrier

signal, allows the circuit for pulse width modulation to be simplified

**[0014]** In one embodiment, the carrier signal is a sawtooth wave signal having a generally constant amplitude.

5 **[0015]** According to the second aspect of the present invention, there is provided a control method for converting a

virtue of its constant carrier amplitude, and suitable for digital control systems by virtue of its capability of maintaining the PWM modulation resolution constant. Moreover, the matrix converter, in which the sawtooth wave  
5 signal is used as the carrier signal, allows carrier generation and modulation processing to be simplified.

[0016] One embodiment further comprises:

a holding section for holding the output voltage command signal corrected by the signal correcting section  
10 and power supply voltage information, wherein

the holding section updates the output voltage command signal and the power supply voltage information at a timing of a peak of the carrier signal, and

the PWM conversion signal generating section  
15 generates the PWM conversion signal based on the output voltage command signal and the power supply voltage information held by the holding section.

[0017] In this embodiment, update of the output voltage command signal and the power supply voltage information is  
20 synchronized at the timing of the peak of the carrier signal, thus making it possible to prevent occurrence of current distortions as well as to achieve simplification of the control-related construction.

[0018] According to the present invention, there is  
25 provided a matrix converter control method for converting a

three-phase ac input voltage into a specified three-phase ac output voltage, comprising the steps of:

generating an output voltage command signal for outputting the specified three-phase ac output voltage by an output voltage command signal generating section;

generating a signal representing a current flow ratio by a current flow ratio generating section based on a specified input current command signal;

correcting, by a signal correcting section, the output voltage command signal generated by the output voltage command signal generating section based on the output voltage command signal and the signal representing the current flow ratio generated by the current flow ratio generating section;

generating a PWM conversion signal by a PWM conversion signal generating section based on the output voltage command signal corrected by the signal correcting section and a carrier signal; and

converting the three-phase ac input voltage into the specified three-phase ac output voltage by a conversion section based on the PWM conversion signal generated by the PWM conversion signal generating section, wherein

given the input current command signals are represented by  $i_r^*$ ,  $i_s^*$ ,  $i_t^*$  and a voltage command is represented by  $V_s^*$ , assuming the lowest voltage phase as a

reference voltage when a polarity of a mid phase out of the  
output voltage command signal is positive or the highest  
voltage phase as a reference voltage when the polarity of  
the mid phase out of the output voltage command signal is  
5 negative, the current flow ratio generating section  
generates the current flow ratio of the maximum phase by

$$V_s^* \frac{2}{\sqrt{3}} \text{mid}(|i_r^*|, |i_s^*|, |i_t^*|)$$

and generates a sum of the current flow ratio of the maximum  
phase and the current flow ratio of the mid phase by

$$V_s^* \frac{2}{\sqrt{3}} \max(|i_r^*|, |i_s^*|, |i_t^*|).$$

**[0019]** In this matrix converter control method, based on  
10 the output voltage command signal generated by the output  
voltage command signal generating section and the signal

representing the current flow ratio generated by the current flow ratio generating section, the output voltage command signal is corrected by the signal correcting section. Based on the corrected output voltage command signal and the carrier signal, the PWM modulation signal is generated by the PWM modulation signal generating section. With such a modulation method by input current flow ratio, a constant average virtual dc link voltage can be obtained and, as a result, the control-related circuit construction can be simplified without involving such computations as ripple computation or carrier amplitude modulation.

[0020] As apparent from the above description, according to the matrix converter and the matrix converter control method of the invention, there can be realized a matrix converter in which the control-related circuit construction can be simplified without involving such computations as ripple computation or carrier amplitude modulation.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0021] Fig. 1 is a constructional view of a conversion section of a matrix converter according to an embodiment of the present invention;

Fig. 2 is a block diagram of a control section of the matrix converter;

Figs. 3A-3F are charts showing waveforms of individual sections of the matrix converter;

Fig. 4 is a chart showing turn-on timing of the matrix converter;

5 Figs. 5A and 5B are charts of signal update timing of the matrix converter;

Figs. 6A-6D are charts showing signal update timing of occurrence of distortion;

10 Fig. 7 is a diagram showing a logic circuit of a pulse pattern circuit;

Fig. 8 is a block diagram of a control section in a matrix converter which is a comparative example;

Figs. 9A-9F are charts showing waveforms of individual sections of the matrix converter;

15 Fig. 10 is a chart showing turn-on timing of the matrix converter;

Fig. 11 is a diagram showing a logic circuit of the matrix converter;

20 Figs. 12A-12D are charts showing signal update timing of occurrence of distortion;

Figs. 13A-13D are charts showing effects of carrier cycle in various switching states;

DETAILED DESCRIPTION OF THE INVENTION

[0022]        Hereinbelow, the matrix converter and the matrix converter control method according to the present invention will be described in detail by way of embodiments thereof illustrated in the accompanying drawings.

5        [0023]        Fig. 1 is a constructional view of a matrix converter according to one embodiment of the invention. As shown in Fig. 1, the three-phase to three-phase matrix converter has three ac switches connected to individual phases of a three-phase power supply, respectively, in steps  
10        of output phases, with a view to obtaining variable voltages and variable frequencies by controlling the connection phase and time as required.

[0024]        This matrix converter, as shown in Fig. 1, includes a converter section 1 composed of switches  $S_{ur}$ ,  
15         $S_{us}$ ,  $S_{ut}$ ,  $S_{vr}$ ,  $S_{vs}$ ,  $S_{vt}$ ,  $S_{wr}$ ,  $S_{ws}$ ,  $S_{wt}$ , and a control section 2 (shown in Fig. 2) for outputting signals to turn on and off the switches  $S_{ur}$ ,  $S_{us}$ ,  $S_{ut}$ ,  $S_{vr}$ ,  $S_{vs}$ ,  $S_{vt}$ ,  $S_{wr}$ ,  $S_{ws}$ ,  $S_{wt}$  of the converter section 1.

[0025]        In the converter section 1, a phase voltage  $v_r$   
20        out of three-phase ac input voltages derived from a three-phase ac power supply 3 is inputted to one end of each of the switches  $S_{ur}$ ,  $S_{vr}$ ,  $S_{wr}$ , a phase voltage  $v_s$  out of the three-phase ac input voltages is inputted to one of each of  $S_{us}$ ,  $S_{vs}$ ,  $S_{ws}$ , and a phase voltage  $v_t$  out of the three-  
25        phase ac input voltages is inputted to one end of each of

$S_{ut}$ ,  $S_{vt}$ ,  $S_{wt}$ , respectively. The other ends of the switches  $S_{ur}$ ,  $S_{us}$ ,  $S_{ut}$  are connected to an output terminal of the phase voltage  $v_u$ , the other ends of the switches  $S_{vr}$ ,  $S_{vs}$ ,  $S_{vt}$  are connected to an output terminal of the phase voltage  $v_r$ , and the other ends of the switches  $S_{wr}$ ,  $S_{ws}$ ,  $S_{wt}$  are connected to an output terminal of the phase voltage  $v_w$ .

[0026] Also, Fig. 2 shows a block diagram of the control section 2.

10 [0027] The control section 2, as shown in Fig. 2, includes: a line voltage control command signal generating section 11 as an example of an output voltage command signal generating section for generating a line voltage control command signal based on output voltage command signals  $V_u^*$ ,  $V_v^*$ ,  $V_w^*$  and an input voltage  $V_{mid}$ ; a current flow ratio generating section 12 for computing a current flow ratio based on input current command signal  $i_r^*$ ,  $i_s^*$ ,  $i_t^*$ ; a command signal computing section 13 as an example of a signal correcting section for computing a maximum phase + mid phase command signal and a mid phase command signal based on a line voltage control command signal generated by the line voltage control command signal generating section 11 and a current flow ratio computed by the current flow ratio generating section 12; an S/H (sample-hold) section 14 for updating and holding a maximum

phase + mid phase command signal and a mid phase command  
signal derived from the command signal computing section 13  
at a timing of a peak of a carrier signal; a carrier  
comparison section 15 which has a carrier signal generation  
5 circuit 20 for generating the carrier signal and which  
performs a comparison between the maximum phase + mid phase  
command signal held by the S/H section 14 and the carrier  
signal, as well as a comparison between the mid phase  
command signal and the carrier signal; an S/H (sample-hold)  
10 section 16 for updating and holding power supply voltage  
phase information  $V_{\max}$ ,  $V_{\text{mid}}$ ,  $V_{\min}$  and a reference voltage  
X/Y at a timing of a peak of a carrier signal derived from  
the carrier signal generation circuit 20; and a pulse  
pattern generating section 17 for generating a pulse  
15 pattern (PWM conversion signal) for turning on and off the  
switches  $S_{ur}$ ,  $S_{us}$ ,  $S_{ut}$ ,  $S_{vr}$ ,  $S_{vs}$ ,  $S_{vt}$ ,  $S_{wr}$ ,  $S_{ws}$ ,  $S_{wt}$  based  
on comparison results from the carrier comparison section  
15 and the power supply voltage phase information  $V_{\max}$ ,  
 $V_{\text{mid}}$ ,  $V_{\min}$  and the reference voltage X/Y held in the S/H  
20 section 16.

[0028] The command signal computing section 13 has a  
maximum phase + mid phase command signal computing section  
13a for multiplying a line voltage control command signal  
derived from the line voltage control command signal  
25 generating section 11 by a maximum phase + mid phase

command signal, and a mid phase command signal computing section 13b for multiplying the line voltage control command signal by a mid phase command signal.

[0029] The carrier comparison section 15 and the pulse  
5 pattern generating section 17 constitute a PWM conversion signal generating section. Also, the S/H section 14 and the S/H section 16 constitute a hold section.

[0030] (Comparative Example)

Fig. 8 shows a block diagram of a control section  
10 in a matrix converter which is a comparative example. It is noted that the matrix converter shown in Fig. 8 is given for an easier understanding of the present invention, and neither a known or prior art nor a matrix converter of the invention.

[0031] The control section of the matrix converter in  
15 this Comparative Example, as shown in Fig. 8, includes: a line voltage control command signal generating section 101 for generating a line voltage control command signal based on output voltage command signals  $V_u^*$ ,  $V_v^*$ ,  $V_w^*$  and a  
20 current distribution ratio 'a'; a voltage ripple computing section 102 for computing a voltage ripple based on input voltages  $V_{max}$ ,  $V_{mid}$ ,  $V_{min}$ ; a current distribution ratio computing section 103 for computing a current distribution ratio 'a' based on input current command signals  $i_{max}^*$ ,  
25  $i_{mid}^*$ ,  $i_{min}^*$ ; a command signal computing section 104 for

computing maximum phase + mid phase command signal and a  
maximum phase command signal based on a line voltage  
control command signal generated by the line voltage  
control command signal generating section 11 and a current  
5 distribution ratio 'a' computed by the current distribution  
ratio computing section 103; a carrier comparison section  
105 which has a carrier signal generation circuit 120 for  
generating a carrier signal and which performs a comparison  
between the maximum phase + mid phase command signal  
10 derived from the command signal computing section 104 and  
the carrier signal, as well as a comparison between the  
maximum phase command signal and the carrier signal; a  
switching section 106 for outputting a switching signal  
based on a comparison result from the carrier comparison  
15 section 105; an S/H section 107 for updating and holding  
voltage command phase information  $\theta_r$  derived from the line  
voltage control command signal generating section 101 and  
power supply voltage phase information  $V_{max}$ ,  $V_{mid}$ ,  $V_{min}$   
based on a Bas-level switching signal from the switching  
20 section 106; an S/H section 108 for updating and holding a  
reference voltage X/Y based on a Top-level switching signal  
from the switching section 106; and a pulse pattern  
generating section 109 for generating a pulse pattern (PWM  
conversion signal) to turn on and off the switches  $S_{ur}$ ,  
25  $S_{us}$ ,  $S_{ut}$ ,  $S_{vr}$ ,  $S_{vs}$ ,  $S_{vt}$ ,  $S_{wr}$ ,  $S_{ws}$ ,  $S_{wt}$  of the conversion

section based on a comparison result from the carrier comparison section 105 as well as the voltage command phase information  $\theta_r$  and the power supply voltage phase information  $V_{\max}$ ,  $V_{\text{mid}}$ ,  $V_{\min}$  and the reference voltage X/Y held in the S/H sections 107, 108.

[0032] The carrier signal generation circuit 120 of the carrier comparison section 105 performs amplitude modulation of a carrier signal based on a voltage ripple signal derived from the voltage ripple computing section 102.

[0033] Figs. 9A-9F show waveforms of individual sections by the matrix converter control method of the Comparative Example, where the input power factor is assumed to be 1 and the output frequency is assumed as equal to that of the power supply for simplicity's sake. In this case, with regard to a magnitude relationship of three-phase ac potential, the mid phase potential is inverted in polarity in every 60-degree phase angle. Therefore, under the condition that based on the polarity of the mid phase voltage (positive: region X, negative: region Y), a reference waveform (minimum phase for the region X, maximum phase for the region Y) is changed, potentials with respect to the reference waveform are

$$\begin{aligned} X : E_{\max} &= V_{\max} - V_{\min}, & E_{\text{mid}} &= V_{\text{mid}} - V_{\min} \\ Y : E_{\max} &= V_{\min} - V_{\max}, & E_{\text{mid}} &= V_{\text{mid}} - V_{\max} \end{aligned}$$

where it is understood that two potentials can be obtained.

[0034] Meanwhile, with respect to the command signal, a two-phase modulation waveform resulting from dividing a three-phase voltage command by a minimum phase is used. In this case, in the region Y, in which the potential becomes negative, the polarity is inverted to change over the waveform to one resulting from division by the maximum phase. From matching of the output voltage polarity in this way, the virtual dc link voltage results in a relationship expressed by the following equations:

$$\begin{aligned} X : E_{\max} &= V_{\max} - V_{\min}, \quad E_{\text{mid}} = V_{\text{mid}} - V_{\min} \\ Y : E_{\max} &= -(V_{\min} - V_{\max}), \quad E_{\text{mid}} = -(V_{\text{mid}} - V_{\max}) \end{aligned}$$

where pulsating currents by two potentials shown in Fig. 9B are modulated.

[0035] Next, the method for apportioning the command signal into two signals is defined by the current distribution ratio, which is a ratio of the mid phase current to the maximum phase current. Given a semi-cycle T of the carrier signal, a time  $T_0$  from a peak of the carrier signal to a switching to the mid phase, and a time  $T_1$  from a peak of the carrier signal to a switching to the maximum phase, the current distribution ratio 'a' is expressed by

$$\begin{aligned} a &= C2/C1 \\ C1 &= T - T_1 \\ C2 &= T_1 - T_0. \end{aligned}$$

In this case, because of the expression with a power factor of 1, the ratio of phase voltage is used in Fig. 9A.

[0036] Time ratios of connection to the maximum phase voltage and the mid phase voltage are determined by the following equations. In this connection, since the maximum phase value is multiplied by a voltage command value and the mid phase value is multiplied by a current distribution ratio, an average virtual dc link voltage is defined by a value resulting from addition of the mid voltage to the maximum voltage at a current distribution ratio.

$$\text{Max. phase} : (T - T_1) / T = V_s^* / V_{tri} \cdots (1)$$

$$\text{Mid phase} : (T_1 - T_0) / T = a V_s^* / V_{tri} \cdots (2)$$

$$\text{Max. + mid phase} : (T - T_0) / T = (1 + a) V_s^* / V_{tri} \cdots (3)$$

$$\text{Carrier amplitude} : V_{tri} = E_{\max} + a E_{\text{mid}}$$

[0037] In this case, for the region X, the phase of the lowest voltage out of the output voltage command signals  $V_u^*$ ,  $V_v^*$ ,  $V_w^*$  is assumed as the reference voltage  $V_s^*$ , while for the region Y, a voltage command in which the phase of the highest voltage out of the output voltage command signals  $V_u^*$ ,  $V_v^*$ ,  $V_w^*$  is taken as the reference voltage is assumed as  $V_s^*$ .

[0038] Therefore, the pulsating current is compensated by amplitude modulation of the carrier signal with the average virtual dc link voltage, and then PWM modulation through carrier comparison is performed with two command

signals at conduction timing shown in Fig. 10. In this case, patterns of gating to one-phase portions of the maximum, mid and minimum phases are isolated by using the following logical equations:

$$\text{Max. phase} : X = (V_{tri} < V_s^*)$$

$$\text{Min. phase} : Z = (V_{tri} > (1+a)V_s^*)$$

$$\text{Mid phase} : Y = \overline{(X \cup Z)}.$$

5 [0039] With respect to the input phase of connection, as shown in Fig. 11, gate signals for the respective switches are apportioned by logical circuits based on logic signals showing the magnitude relationships among the individual phases.

10 [0040] In the matrix converter of this Comparative Example, since modulation is performed by multiplying both command signal and carrier signal by factors with the use of the current distribution ratio 'a', there has been a problem that the control configuration or computations  
15 would be complicated.

[0041] In the matrix converter of the Comparative Example, the ratio of the mid phase to the maximum phase would be defined as the current distribution ratio. However, in the present invention, the current is  
20 distributed with a normalized current value.

[0042] Figs. 3A-3F show normalized current waveforms in the matrix converter of the invention, where it is assumed

that shunting with C1 is applied to the maximum phase and shunting with C2 is applied to the mid phase. Since the maximum phase is assumed as 1 in the method of the foregoing Comparative Example, multiplying by a factor of 2/√3 to set 1 on the boundary of the region X and the region Y causes flow ratios among the individual phases to be expressed by the following relationship:

$$\text{Max. phase} : (T - T_1) / T = V_s^* \frac{2}{\sqrt{3}} \text{mid}(|i_r^*|, |i_s^*|, |i_t^*|) \cdots (4)$$

$$\text{Mid phase} : (T_1 - T_0) / T = V_s^* \frac{2}{\sqrt{3}} \text{min}(|i_r^*|, |i_s^*|, |i_t^*|) \cdots (5)$$

$$\text{Max. + mid phase} : (T - T_0) / T = V_s^* \frac{2}{\sqrt{3}} \text{max}(|i_r^*|, |i_s^*|, |i_t^*|) \cdots (6).$$

[0043] In this case, for the region X, the phase of the lowest voltage out of the output voltage command signals  $V_u^*$ ,  $V_v^*$ ,  $V_w^*$  is assumed as the reference voltage  $V_s^*$ , while for the region Y, a voltage command in which the phase of the highest voltage out of the output voltage command signals  $V_u^*$ ,  $V_v^*$ ,  $V_w^*$  is taken as the reference voltage is assumed as  $V_s^*$ . Although a sum of flow ratios of the maximum phase and the mid phase becomes over 1, the voltage control rate of the maximum voltage command results from the virtual dc link voltage waveform as:

$$\cos 30^\circ = \frac{\sqrt{3}}{2}$$

Thus, the maximum value of flow ratios results in 1 eventually.

[0044] Multiplying two potentials of the virtual dc link by the above flow ratio results in an average virtual dc link voltage waveform. Since a constant dc voltage is obtained as shown in Fig. 3F, it can be understood that  
5 amplitude modulation of the carrier signal as in the Comparative Example is unnecessary.

[0045] Fig. 4 shows a chart for explaining the conduction timing described above. At the conduction timing shown in Fig. 4, PWM modulation by carrier  
10 comparison is performed.

[0046] Next, it is shown that the same results as in the Comparative Example can be obtained by the method of the invention. It is noted that the power factor is assumed as 1, and the description will be given by phase voltage.

15 [0047] For intervals with the phase angle ranging from  $30^\circ$  to  $60^\circ$ , it follows that

$$E_{\max} = V_{\max} - V_{\min} = V_r - V_t = \frac{1}{\sqrt{3}}(\cos\theta_r - \cos\theta_t) = \cos\phi$$
$$E_{\text{mid}} = V_{\text{mid}} - V_{\min} = V_s - V_t = \frac{1}{\sqrt{3}}(\cos\theta_s - \cos\theta_t) = \cos(\phi - \pi/3).$$

In this case, since

$$a = \frac{\cos \theta_s}{\cos \theta_r}$$

$$\phi = \theta - \pi/6$$

$$V_r = \frac{1}{\sqrt{3}} \cos \theta_r = \frac{1}{\sqrt{3}} \cos \theta$$

$$V_s = \frac{1}{\sqrt{3}} \cos \theta_s = \frac{1}{\sqrt{3}} \cos(\theta - \frac{2\pi}{3}),$$

$$V_t = \frac{1}{\sqrt{3}} \cos \theta_t = \frac{1}{\sqrt{3}} \cos(\theta + \frac{2\pi}{3})$$

modifying Equation (1) results in

$$\begin{aligned} \frac{1}{E_{\max} + aE_{\text{mid}}} &= \frac{1}{\cos \phi + \frac{\cos \theta_s}{\cos \theta_r} \cos(\phi - \pi/3)} \\ &= \frac{\cos \theta_r}{\cos \theta_r \cos \phi + \cos \theta_s \cos(\phi - \pi/3)} \\ &= \frac{\cos \theta_r}{\sin(\pi/3 - \phi) \cos \phi + \sin \phi \cos(\phi - \pi/3)} \\ &= \frac{2 \cos \theta_r}{\sin \pi/3 + \sin(\pi/3 - 2\theta) + \sin(2\theta - \pi/3) + \sin \pi/3} \\ &= \frac{2}{\sqrt{3}} \cos \theta_r. \end{aligned}$$

[0048] Accordingly, the mid phase flow ratio is

$$\frac{a}{E_{\max} + aE_{\text{mid}}} = \frac{2}{\sqrt{3}} \cos \theta_s$$

and the sum of flow ratios for the maximum phase and the mid phase is

$$\frac{1+a}{E_{\max} + aE_{\text{mid}}} = -\frac{2}{\sqrt{3}} \cos \theta_t$$

5 thus consistent with Equations (4), (5) and (6).

[0049] The matrix converter of the invention shown in Fig. 2, as compared with the matrix converter of the

Comparative Example of Fig. 8, becomes constant in average virtual dc link voltage, eliminating the needs for blocks associated with the voltage ripple computation and the carrier amplitude modulation, so that its construction can be simplified.

**[0050]** Although Equations (4) and (6) are shown as blocks for determining current flow ratios, yet it is also possible to further simplify the construction by looking up to a single sine table for the determination of mid and maximum values with the use of a phase angle  $\phi$  within the region X or region Y:

$$\left. \begin{aligned} \frac{2}{\sqrt{3}} \text{mid}(|i_r^*|, |i_s^*|, |i_t^*|) &= \frac{2}{\sqrt{3}} \sin(\pi/3 - \phi) \quad (\text{where } \pi/6 > \phi \geq 0) \\ &= \frac{2}{\sqrt{3}} \sin \phi \quad (\text{where } \pi/3 > \phi \geq \pi/6) \end{aligned} \right\} \dots (7)$$

$$\frac{2}{\sqrt{3}} \text{max}(|i_r^*|, |i_s^*|, |i_t^*|) = \frac{2}{\sqrt{3}} (\sin \phi + \sin(\pi/3 - \phi)) \dots (8).$$

**[0051]** Also, a case with the power factor of 1 only is shown above, and the switching of the region X and Y is performed by referencing the polarity of the mid phase of the power supply voltage (three-phase ac input voltage). However, when the input power factor is variable, it is also possible to control the power factor by switching with a phase of the mid phase to which a phase difference is added.

**[0052]** In the matrix converter of the Comparative Example of Fig. 8, because the voltage command has a two-

phase modulation waveform, the maximum phase and the mid phase out of the voltage command are subjected to PWM modulation, and apportioning to the individual phases is performed by using phase information  $\theta_r$ . Further, as a  
5 measure for a case where the synchronism between power supply frequency and carrier frequency is not ensured, updating timing is limited to the reference voltage X/Y, the voltage command phase information  $\theta_r$  and the power supply voltage phase information  $V_{\max}$ ,  $V_{\text{mid}}$ ,  $V_{\min}$ .

10 [0053] Figs. 12A to 12D show timings at which distortion occurs in a case where the matrix converter of the Comparative Example is asynchronous. In this case, distortion occurs to three points of change, i.e. change of reference voltage, phase shift of the two-phase modulation  
15 waveform, and phase shift of the power supply voltage (current).

[0054] Figs. 13A to 13D show effects on the above changes in individual switching states (maximum, mid and minimum) of the carrier cycle. These figures are shown by  
20 single-phase output for simplicity, where the phase having only one phase short-circuited by bold line is the 120° conduction phase of the two-phase modulation waveform while the other is any two phases. In the initial state, it is assumed that the maximum, mid and minimum voltages  
25 correspond to r phase, s phase and t phase, respectively.

[0055] (1) State of conduction to the maximum phase  
(shown in Fig. 13B)

As the reference voltage X/Y changes, voltage  
command values of U and V phases are inverted while  
5 switching signals of r and t phases are switched over. As  
a result, the state changes from X (+-) to Y (-+), whereas  
neither U nor V phase changes in switching state to the  
maximum and minimum phases.

[0056] In a case where the conduction phase and the  
10 switching phase have changed due to a phase shift of the  
voltage command phase information  $\theta_r$ , switching between U  
phase and V phase causes the state to change from X(+-) to  
X(-+) so that the output changes from r phase to t phase.

[0057] With regard to the power supply voltage phase  
15 information  $V_{max}$ ,  $V_{mid}$ ,  $V_{min}$ , when the maximum phase and  
the mid phase of the input voltage have been switched (r  
phase  $\leftrightarrow$  s phase), the switch for the U phase to conduct  
changes from  $S_{ur}$  to  $S_{us}$ .

[0058] (2) State of conduction in the mid phase (shown  
20 in Fig. 13C)

When the reference voltage X/Y has changed, the  
state changes from X(+-) to Y(-+), so that both U phase and  
V phase change in switching state.

[0059] As a result of a phase shift of the voltage  
25 command phase information  $\theta_r$ , the state changes from X(+-)

to  $X(-+)$ , so that both U phase and V phase change in switching state.

[0060] As to the power supply voltage phase information  $V_{\max}$ ,  $V_{\text{mid}}$ ,  $V_{\min}$ , when the maximum phase and the mid phase  
5 of the input voltage have been switched, the switch for the U phase to conduct changes from  $S_{us}$  to  $S_{ur}$ .

[0061] (3) State of conduction to the minimum phase (shown in Fig. 13D)

When the reference voltage X/Y has changed, the  
10 state changes from  $X(+-)$  to  $Y(-+)$ , so that both U phase and V phase change in switching state.

[0062] As a result of a phase shift of the voltage command phase information  $\theta_r$ , the state changes from  $X(+-)$  to  $X(-+)$ , whereas the switching state does not change  
15 because both U phase and V phase are in the minimum phase.

[0063] With regard to the power supply voltage phase information  $V_{\max}$ ,  $V_{\text{mid}}$ ,  $V_{\min}$ , when the maximum phase and the mid phase of the input voltage have been switched, the switching state does not change because both U phase and V  
20 phase are in the minimum phase.

[0064] As shown above, in the matrix converter of the Comparative Example, because of the presence of a mode in which a change of the signals does not cause a change of the switching state, it is permitted to update the  
25 reference voltage X/Y during the period of conduction to

the maximum phase (Top), and the voltage command phase information  $\theta_r$  and the power supply voltage phase information  $V_{max}$ ,  $V_{mid}$ ,  $V_{min}$  during the period of switching to the minimum phase (Bas), so that balance of current distribution within the carrier cycle is ensured. Also, for the updating periods therefor are used a voltage command mid phase signal that minimizes the conduction period to the power supply maximum phase (Top) as well as a voltage command maximum phase signal that minimizes the conduction period to the power supply minimum phase (Bas).

[0065] In the matrix converter of the Comparative Example, since the voltage command has a two-phase modulation waveform, the three-phase voltage command is not used, and only the maximum phase and the mid phase are subjected to PWM modulation, where phase information  $\theta_r$  is used for apportioning to the individual phases. Therefore, not only the reference voltage X/Y and the power supply voltage phase information ( $V_{max}$ ,  $V_{mid}$ ,  $V_{min}$ ), which are subject to update limitations to avoid distortions due to asynchronism, but also phase information needs to be subject to update limitation. Further, update control involves the use of two signal levels, i.e. a mid phase signal and a maximum phase signal, giving rise to a problem of complicated construction of the control system.

[0066] In the digital control of inverters, signal input and output are controlled in synchronization with the timing of PWM carrier cycles in order to take matching of signal delay time.

5 [0067] In this connection, in the matrix converter of the invention, on the assumption that a signal wave to be modulated is updated and held at the timing of a peak of the carrier signal as shown in Fig. 5, the signal is switched in a state of conduction to the minimum phase. In  
10 this case, the voltage command phase information  $\theta_r$  and the power supply voltage phase information  $V_{max}$ ,  $V_{mid}$ ,  $V_{min}$  correspond to updatable timings, whereas the invention uses the three-phase voltage command, containing phases, so that update control for the phase information  $\theta_r$  becomes  
15 unnecessary. The power supply voltage phase information  $V_{max}$ ,  $V_{mid}$ ,  $V_{min}$  is updated in synchronization with the timing of a peak of the carrier signal.

[0068] Also in this invention, the reference voltage X/Y is updated at the timing of a peak of the carrier signal as  
20 well. The timing of a peak of the carrier signal corresponds to the minimum phase, where update control would be performed by level signals, in conventional cases, so that the input current distribution within the carrier cycle is unbalanced as shown in Fig. 6A and 6B. On the  
25 other hand, as to the update in the maximum phase, there

occurs no changes in switching state with respect to the changeover of the reference voltage X/Y as shown in Fig. 6C and 6D.

[0069] Changes in switching state by update timing in this invention are shown in Fig. 5A and 5B. In this case, with respect to the minimum phase level signal, waveform update is performed at the timing of a peak of the carrier signal. As a result, whereas the switching state of the maximum phase and the minimum phase is changed, the waveform is maintained symmetrical, making it understood that current distribution of a half carrier cycle keeps equal, as compared with the updated waveform in the maximum phase.

[0070] As shown above, update of the reference voltage X/Y and the power supply voltage phase information  $V_{\max}$ ,  $V_{\text{mid}}$ ,  $V_{\min}$  is synchronized at the timing of a peak of the carrier signal in which the voltage command is updated and held, thus making it possible to prevent occurrence of current distortions as well as to achieve simplification of the control-related construction.

[0071] In addition, the update of control information in the pulse pattern generating section 17 of Fig. 2 can be provided by using such a circuit as shown in Fig. 7 as an example.

[0072] According to the matrix converter of this embodiment, the average virtual dc link voltage is made constant by the modulation method with the use of input current flow ratio, eliminating the needs for ripple computation and computations for carrier amplitude modulation, so that the control-related construction can be simplified.

[0073] Further, the matrix converter is easily applicable to digital counters and comparators by virtue of its constant carrier amplitude, and suitable for digital control systems by virtue of its capability of maintaining the PWM modulation resolution constant.

[0074] Moreover, the matrix converter is enabled to reduce input current distortions even in cases of asynchronism of three-phase ac input voltage and carrier cycle, with a simple construction in which the output voltage command and the power supply voltage (current) information are updated and held at the timing of carrier peaks.

WHAT IS CLAIMED IS:

1. A matrix converter for converting a three-phase ac input voltage into a specified three-phase ac output voltage, comprising:

5 an output voltage command signal generating section for generating an output voltage command signal to output the specified three-phase ac output voltage;

a current flow ratio generating section for generating a signal representing a current flow ratio based on a specified input current command signal;

10 a signal correcting section for correcting the output voltage command signal based on the output voltage command signal generated by the output voltage command signal generating section and the signal representing the current flow ratio generated by the current flow ratio generating section;

15 a PWM conversion signal generating section, for generating a PWM conversion signal based on the output voltage command signal corrected by the signal correcting section and a carrier signal; and

20 a conversion section for converting the three-phase ac input voltage into the specified three-phase ac output voltage based on the PWM conversion signal

generated by the PWM conversion signal generating section ,  
wherein

given the input current command signals are  
represented by  $i_r^*$  ,  $i_s^*$  ,  $i_t^*$  and a voltage command is  
5 represented by  $V_s^*$  , assuming the lowest voltage phase as a  
reference voltage when a polarity of a mid phase out of the  
output voltage command signal is positive or the highest  
voltage phase as a reference voltage when the polarity of  
the mid phase out of the output voltage command signal is  
10 negative, the current flow ratio generating section  
generates the current flow ratio of the maximum phase by

$$V_s^* \frac{2}{\sqrt{3}} \text{mid}(|i_r^*|, |i_s^*|, |i_t^*|)$$

and generates a sum of the current flow ratio of the maximum  
phase and the current flow ratio of the mid phase by

$$V_s^* \frac{2}{\sqrt{3}} \max(|i_r^*|, |i_s^*|, |i_t^*|).$$

2. The matrix converter as claimed in Claim 1,  
15 wherein

given that the input current command signals are  
represented by  $i_r^*$  ,  $i_s^*$  ,  $i_t^*$  and that a phase angle of  
the input current command signals  $i_r^*$  ,  $i_s^*$  ,  $i_t^*$  relative  
to the output voltage command signal is represented by  $\phi$  ,

the current flow ratio generating section generates the current flow ratio of the maximum phase by

$$\begin{aligned}\frac{2}{\sqrt{3}}\text{mid}(|i_r^*|, |i_s^*|, |i_t^*|) &= \frac{2}{\sqrt{3}}\sin(\pi/3 - \phi) \quad (\text{where } \pi/6 > \phi \geq 0) \\ &= \frac{2}{\sqrt{3}}\sin\phi \quad (\text{where } \pi/3 > \phi \geq \pi/6)\end{aligned}$$

and generates a sum of the current flow ratio of the maximum phase and the current flow ratio of the mid phase by

$$\frac{2}{\sqrt{3}}\text{max}(|i_r^*|, |i_s^*|, |i_t^*|) = \frac{2}{\sqrt{3}}(\sin\phi + \sin(\pi/3 - \phi)).$$

5        3.            The matrix converter as claimed in Claim 1 or 2, wherein

             the carrier signal is a triangle wave signal having a generally constant amplitude.

10       4.            The matrix converter as claimed in Claim 1 or 2, wherein

             the carrier signal is a sawtooth wave signal having a generally constant amplitude.

15       5.            The matrix converter as claimed in Claim 3 or 4, further comprising

a holding section for holding the output voltage  
command signal corrected by the signal correcting section  
and power supply voltage information, wherein the  
holding section updates the output voltage command signal  
5 and the power supply voltage information at a timing of a  
peak of the carrier signal, and

the PWM conversion signal generating section generates the PWM conversion signal based on the output voltage command signal and the power supply voltage information held by the holding section.

5

6. A matrix converter control method for converting a three-phase ac input voltage into a specified three-phase ac output voltage, comprising the steps of:

generating an output voltage command signal for  
10 outputting the specified three-phase ac output voltage by an output voltage command signal generating section;

generating a signal representing a current flow ratio by a current flow ratio generating section based on a specified input current command signal;

15 correcting, by a signal correcting section, the output voltage command signal generated by the output voltage command signal generating section based on the output voltage command signal and the signal representing the current flow ratio generated by the current flow ratio  
20 generating section;

generating a PWM conversion signal by a PWM conversion signal generating section based on the output voltage command signal corrected by the signal correcting section and a carrier signal; and

converting the three-phase ac input voltage into the specified three-phase ac output voltage by a conversion section based on the PWM conversion signal generated by the PWM conversion signal generating section, wherein given the  
5 input current command signals are represented by  $i_r^*$ ,  $i_s^*$ ,  $i_t^*$  and a voltage command is represented by  $V_s^*$ , assuming the lowest voltage phase as a reference voltage when a polarity of a mid phase out of the output voltage command signal is positive or the highest voltage phase as  
10 a reference voltage when the polarity of the mid phase out of the output voltage command signal is negative, the current flow ratio generating section generates the current flow ratio of the maximum phase by

$$V_s^* \frac{2}{\sqrt{3}} \min(|i_r^*|, |i_s^*|, |i_t^*|)$$

and generates a sum of the current flow ratio of the maximum  
15 phase and the current flow ratio of the mid phase by

$$V_s^* \frac{2}{\sqrt{3}} \max(|i_r^*|, |i_s^*|, |i_t^*|).$$