# Novel Technologies for Power Conversion Circuits

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## 1. Introduction

Variable speed controllers for general-purpose inverters have progressively been of higher quality, smaller size, lighter weight and lower cost. These developments have been accomplished by such progressive technologies as power devices. A control method and the control devices necessary to realize this method, and other technologies including cooling and mounting. However, the main circuit of the inverter is still widely used without any remarkable changes since it was first introduced.

On the other hand, in order to solve the problem of source harmonics, the main circuit for the whole variable speed controller has tended to become more complicate due to the requirements of adding an improving power factor reactor to the diode rectifier and the use of a high power factor converter.

Fuji Electric has been developing a new main circuit for the future variable speed controller. This paper introduces new power conversion circuits and the novel technologies for analyzing them.

## 2. Analysis and Application of the Direct Converter

### 2.1 Features of the direct converter

The purposes of applying the three-phase to three-phase direct converter are as follows:

(1) higher power factor of input current for the power supply
(2) reduction of conduction loss by decreasing the number of conduction devices in the main circuit
(3) compactness and lighter weight by removing parts of the DC link

Figure 1 shows a fundamental circuit of a typical matrix converter in the direct converter. The circuit connects to a total of 9 bi-directional switches, with 3 switches forming a phase. For the direct converter, a directly split up waveform of the input supply voltage as output is used. Therefore, the matrix converter has the maximum controllability of the input supply current and output voltage in the three-phase to three-phase direct converter, because each phase of the output terminal can be selected all phases of the input terminal independently other phases of the output terminal.

### 2.2 Analyzing method of the direct converter

As the circuit of the matrix converter shown in Fig. 1 needs a bi-directional switch, many varieties of circuits are under consideration. A circuit with a fewer number of devices has also been proposed by restricting the function of the matrix converter.

As a result, it is difficult to compare the control characteristics of the many proposed circuits with the same specifications, and a standard analyzing method has not yet been completely established. Fuji Electric has therefore established an analyzing method to evaluate the control characteristics of various circuits to study the direct converter circuit. In this analyzing method, the relationship of input and output voltages

Fig.1 Circuit of the matrix converter

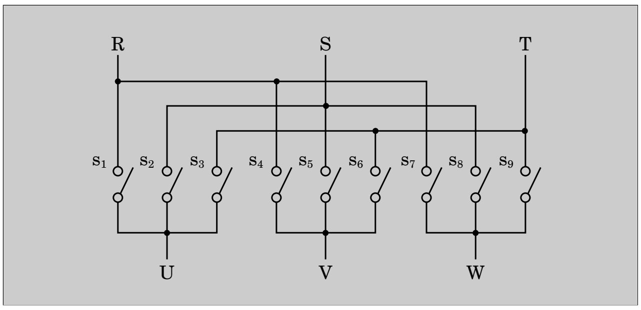



Fig.2 System configuration of the direct converter

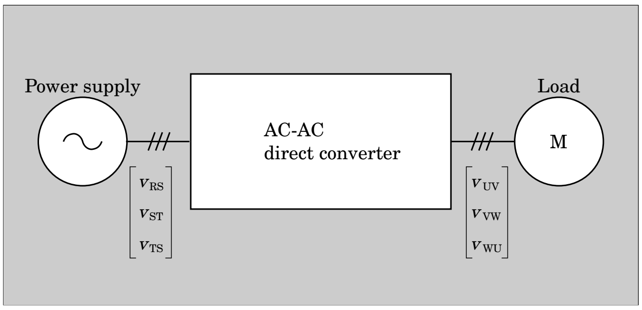


Fig.3 Instantaneous space vectors of the matrix converter

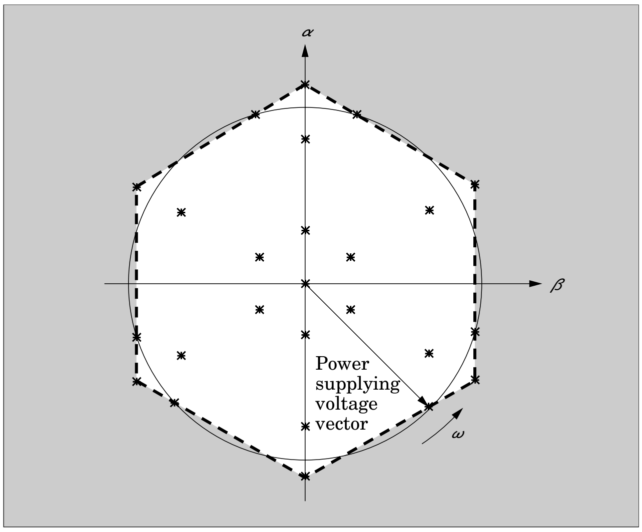



Fig.4 Circuit of the delta converter

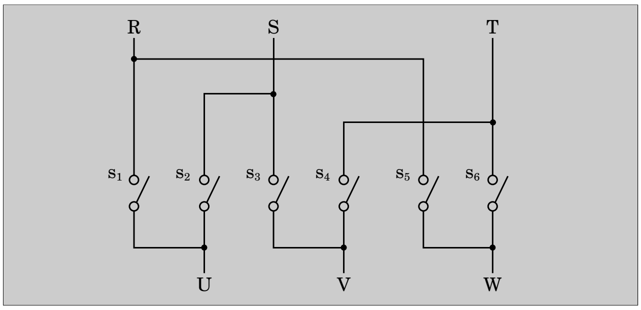
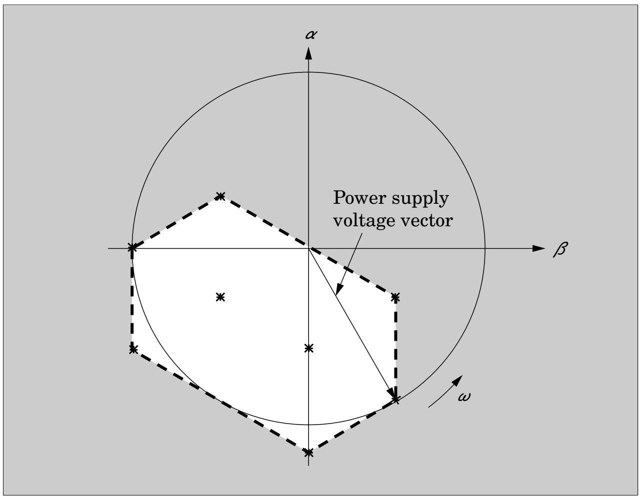



Fig.5 Instantaneous space vectors of the delta converter




of the direct converter shown in Fig. 2 has been defined by using the switching matrix $S$ $(n, m)$. In the case of the three-phase to three-phase direct converter, $S$ is defined as a matrix of 3, 3-type as equation (1).

$$\begin{bmatrix} v_{\mathrm{uv}} \\ v_{\mathrm{vw}} \\ v_{\mathrm{wu}} \end{bmatrix} = \begin{bmatrix} S \\ 3\times 3 \end{bmatrix} = \begin{bmatrix} v_{\mathrm{RS}} \\ v_{\mathrm{ST}} \\ v_{\mathrm{TS}} \end{bmatrix} \quad \text{......} \quad (1)$$

Each element of $S$ is defined as a switching function for each switch. The switching function is defined by the total number of path currents which is based on both input and output voltage.

Subsequently the relationship between input and output supply voltage of the direct converter has been cleared by expressing the instantaneous space vector as an output voltage. Equation (2) shows an operation for the instantaneous space vector of the output voltage.

$$v = \begin{bmatrix} v_{\alpha} \\ v_{\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} S \\ 3\times 3 \end{bmatrix} \begin{bmatrix} v_{\mathrm{RS}} \\ v_{\mathrm{ST}} \\ v_{\mathrm{TS}} \end{bmatrix} \quad \text{......} \quad (2)$$

Equation (3) shows the switch matrix of Fig. 1, and Fig. 3 shows the instantaneous space vectors of the output voltage at a supply voltage phase.

$$S = \begin{bmatrix} s_1 s_5 - s_2 s_4 & s_2 s_6 - s_3 s_5 & s_3 s_4 - s_1 s_6 \\ s_4 s_8 - s_5 s_7 & s_5 s_9 - s_6 s_8 & s_6 s_7 - s_4 s_9 \\ s_2 s_7 - s_1 s_8 & s_3 s_8 - s_2 s_9 & s_1 s_9 - s_3 s_7 \end{bmatrix} \quad \text{......} \quad (3)$$

There are 27 types of vectors, shown with asterisks in Fig. 3, and selection of 3 kinds of switches is possible at one output phase. The circle in Fig. 3 also shows a locus of the supply voltage vector. The dotted line connects to each outer points of the output voltage vectors, and voltage in the region can be output as an average by the PWM. A circle inscribed within the dotted line shows a locus of maximum voltage as far as possible without generation of low order harmonics.

### 2.3 Application examples

Figure 4 shows a circuit with three parts of switches removed from the matrix converter in Fig. 1. The circuit is called a delta converter due to the use of a delta connection for input, as 2 series of bi-directional switches are connected between each line. Analytic examples of the operation by applying the proposed analysis to the delta converter follow.

Equation (4) and Fig. 5 show a switch matrix of the delta converter and a possible output voltage range dependent on both the instantaneous space vector for output voltage at a source phase and the PWM, respectively.

$$S = \begin{bmatrix} s_1 s_3 & s_2 s_4 & -s_1 s_4 \\ -s_6 s_3 & s_3 s_5 & s_4 s_6 \\ s_2 s_6 & -s_2 s_5 & s_1 s_5 \end{bmatrix} \quad \text{......} \quad (4)$$

Because 2 switches are connected to each three-phase of output, the circuit has 8 kinds of output voltage vectors and can control the amplitude of vibration but cannot output an arbitrary frequency. Furthermore, it is able to analyze the possible control range of input current phase with the same analyzing method. From these results, the delta converter is expected to apply equipment for power factor improvement and reduce the starting current in the induction motor. This is because the delta converter is a VVCF (variable voltage constant frequency) circuit which can control the amplitude of vibration in the output voltage while controlling the power factor at 1 for the inductive and capacitive load of up to 120°.

## 3. Direct Linked Type Frequency Changer

### 3.1 Circuit configuration

The matrix converter of the circuit as shown in Fig. 1 requires a bi-directional switch. The switch with the snabber circuit is an AC snabber. Fuji Electric has developed a direct linked type frequency changer which has a basically configured DC clamped type of bilateral switching circuit using a DC snabber (RCD and C snabber). The DC snabber is widely used for inverters and general-purpose IGBT modules.

Figure 6 shows the main circuit configuration. The circuit has the same function as the matrix converter and is capable of both input current and output voltage control. This is because the instantaneous space vector of output voltage is equal to the matrix converter in Fig. 3.

Fig.6 Direct linked type frequency changer

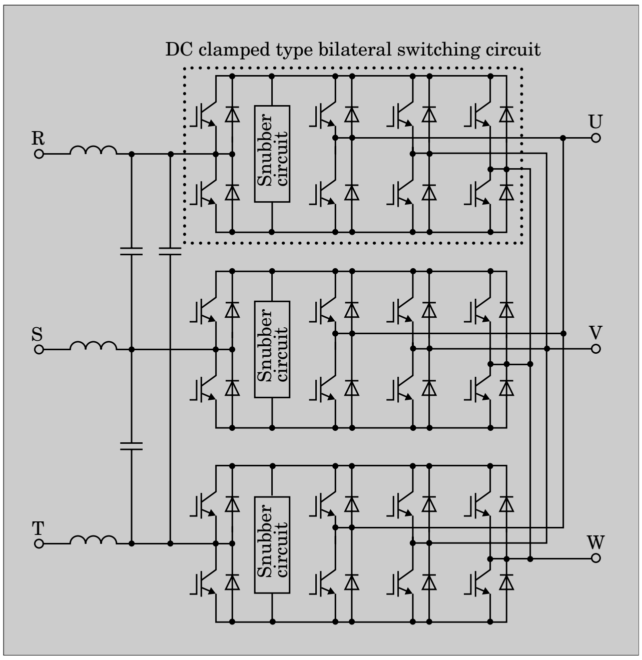
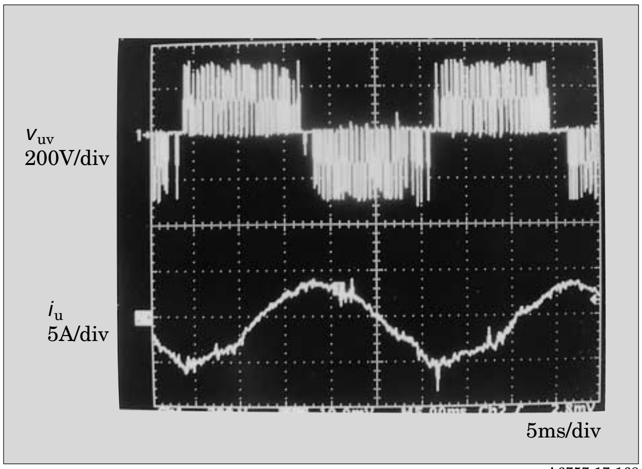



Fig.7 Voltage and current waveform of the direct linked type frequency changer

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### 3.2 Results

Figure 7 shows the output voltage and current waveforms of a general-purpose motor with 3 phase 200V input and 4 poles 2.2kW output and is driven by a main carrier frequency of 16kHz. An applied voltage waveform to the motor has a path swept out by peak value and described as three-phase all-wave. The input voltage waveform is directly split up and distributed. On the other hand, the output current is a sinewave that has performed without problem.

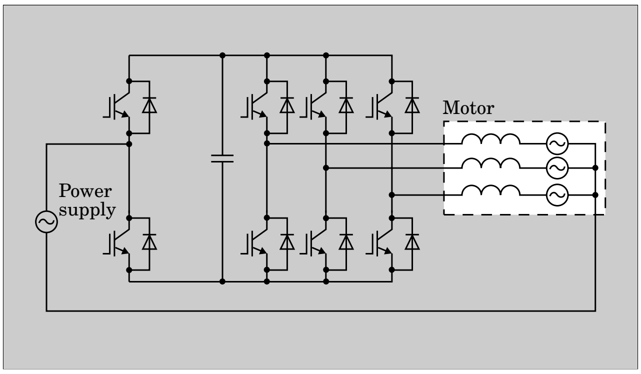
## 4. New Single-Phase High Power Factor Converter

In the case of a single-phase input small-capacity inverter, harmonics generated in the equipment are also regulated by the "Guidelines for the reduction of harmonic emission due to electrical and electronic equipment for household and general use." A single-phase input circuit uses a large reactor inductance for power factor improvement. It requires a large DC link capacitor to absorb double the power ripples as compared with the input frequency. Therefore, the application of a PWM converter has been expected for the circuit to achieve smaller sized equipment and a more perfect sinewave input current. A full-bridge type PWM converter is used when a regeneration function to the power supply is required. Fuji Electric has developed a new single-phase high power factor converter to realize a smaller size and more economical PWM converter. An outline of the circuit will be presented below.

### 4.1 Circuit configuration and operating principle

Figure 8 shows a circuit configuration of the developed full-bridge type new single-phase high power factor converter. The circuit has the same functions as the former full-bridge type PWM converter and it realizes a sinewave curved waveform of supplying

Fig.8 The newest single-phase to three-phase high power factor converter



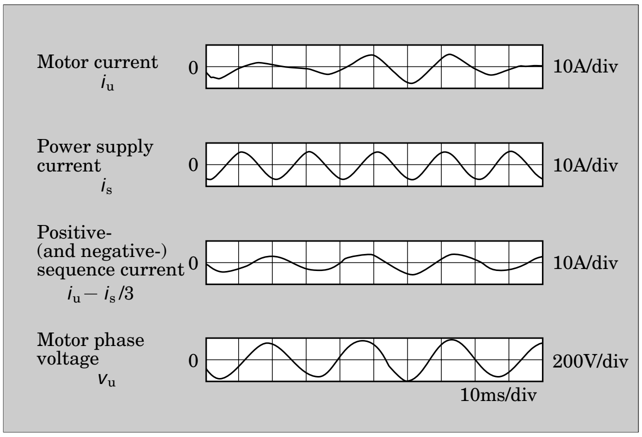
current and recovery of power supply. Features of the circuit include a terminal of single-phase power supply connected to the center of the upper and lower arm in the converter and another terminal connected to a neutral point of the stator coil in the motor driven by the converter. Therefore, a single-phase power supply current supplies the power to the DC link as a zero-sequence current of the motor.

The operating principle of the circuit will now be explained. First, load control of the three-phase induction motor is controlled by voltage control of the three-phase induction motor is controlled by voltage control of the three-phase PWM inverter lines, identical to the former method. The circuit is controlled by selection of the inverter's 2 types of zero-voltage vectors, as the supplying current is realized by the control of the inverter's zero-sequence component. This fact allows the possible elimination of a couple of upper and lower arms from the converter while realizing the same functions as the former full-bridge type PWM converter. The circuit can be reduced in size and cost, as it is able to use leakage inductance of the load motor for the reactance during switching.

### 4.2 Results

Experimental results are shown in Fig. 9 for the variable speed driving general-purpose motor of the 3 phase 200V input and 4 poles 750W output combined new single-phase high power factor converter with a single-phase 100V output. The experiment gives an increased DC link voltage up to 380V and an operated IGBT with 600V blocking capability at 10kHz of carrier frequency and 33Hz output frequency. Output current waveform $i_u$ of the inverter is an added strain current of 50Hz supplying current and 33Hz driving current of the motor. On the other hand, the waveform of the supplying current $i_s$ at the neutral point of the motor is a sinewave waveform. The motor driving current, which is derived from 1/3 of the inverter's supply current, has approximately a sinewave shaped waveform current. This allows for smooth control of the motor's operation.

Fig.9 Voltage and current waveform of the newest single-phase to three-phase high power factor converter




## 5. Conclusion

This paper presented the newest technologies for power conversion circuits for the variable sped controller. These technologies include the analyzing method of the three-phase to three-phase direct converter, the delta converter and the direct linked type frequency changer as the concrete circuit and the new single-phase high power factor converter. Fuji Electric will continue to develop new technologies for the circuit and will offer in a timely manner new products in response to market needs.

### References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