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POWER TRANSISTORIZED THREE-PHASE UNINTERRUPTIBLE POWER SUPPLY

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I. INTRODUCTION

More than fifteen years have passed since the commercialization of constant-voltage, constant-frequency (CVCF) power supply incorporating a thyristor. This type of power supply is now playing an important role as a stable power supply in the fields of totalizator systems, space satellite communications systems, and chemical/iron-making plant process controls as well as on-line systems for banking facilities.

In addition, new CVCF power supply in which newly developed semiconductor elements such as power transistors and turn-off thyristors are employed is now under the process of commercialization, thanks to their striking development in these years, thereby further progress being expected in stationary uninterruptible power supply fields. Especially, power transistors which prossess self circuit interrupting capability do not require auxiliary circuits for commutation, enable to conduct high-speed switching operation, and feature low saturation voltage. They enable to make the circuit structure extremely simple and to make a device compact. lightweight, highly efficient, and low-noised. Moreover, the fact that high DC voltage is not suitable for the system configuration due to use of storage batteries also contributes to popular selection of power transistors as the most appropriate element in the field of uninterruptible power supply.

Fuji Electric has expanded the line of power transistorized uninterruptible power supply step by step since the first application and delivery of power transistors in small capacity uninterruptible power supply in 1977. *Figure 1* reveals the increasing trends in the number delivered and the maximum unit capacity of Fuji's power transistorized uninterruptible power supply units. It will be found that both the number delivered and the maximum unit capacity display a rapid increase in these years. They are operating without any serious troubles.

Table 1 displays the standard series of Fuji Electric's transistorized uninterruptible power supply and the outlines of the threephase units are described hereunder:

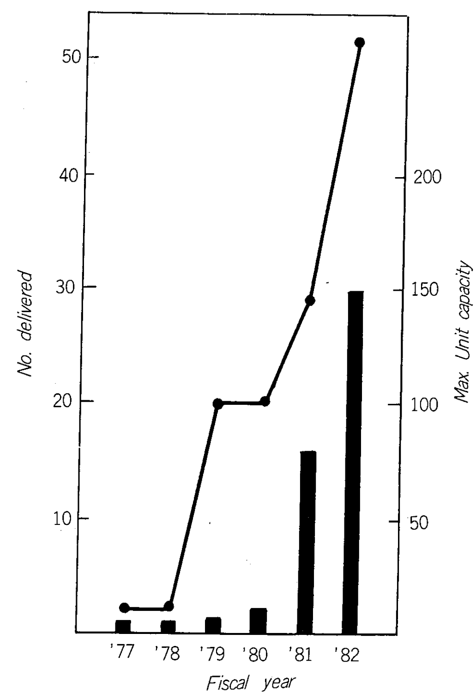


Fig. 1 Number delivered and Max. unit capacity

II. FEATURES

Employing a circuitry in which excellent performance of power transistors is utilized to the maximum extent and based on a variety of new technology, Fuji Electric power transistorized uninterruptible power supply units are provided with the following features:

1. High efficiency

Requiring no auxiliary circuit for commutation and needing small saturation voltage of transistors, the power supply units feature high efficiency as a result of enhanced converting efficiency. The efficiency is improved by about 3 ~ 5 % when compared with conventional models.

2. Compact and lightweight

The three-phase uninterruptible power supply units are

Table 1 Standard series of transistorized uninterruptible power supply

Type \ Capacity (kVA)	DC voltage	1	2	3	5	7.5	10	15	20	30	40	50	60	75	100	125	150	200	250	300	400	500
Single phase 50/60Hz	DC 110V	▽	▽	▽	▽	▽	▽	▽	▽													
	DC220V									▽	▽											
	DC260V								▽	▽	▽	▽	▽									
Three-phase 50/ 60Hz	DC260V								▽	▽	▽	▽		▽	▽	▽	▽					
	DC440V																	▽	▽	▽		
Three-phase 400Hz	DC260V								▽	▽	▽	▽		▽	▽	▽	▽					

Triangles denote the standard capacity

compact and lightweight since no auxiliary circuits for commutation purposes are required and the snubber circuit is minimized due to no dv/dt suppression required. The volume and weight of, for example, 100 kVA units are reduced to about one third of those of conventional models.

3. Low noise

Not incorporating commutation reactor which was a substantial noise source in conventional models, the power-transistorized units produce less noise. When compared with conventional models, the noise is reduced by 5 ~ 10 dB.

4. High reliability

Possessing self circuit interrupting capability, since transistors conduct self circuit interruption, noise which have caused them to effect mis-striking do not affect their performance, thereby operating reliability being extremely high. In addition, the Fuji power transistorized three-phase uninterruptible power supply boasts of high reliability thanks to the Fuji power transistors which posses high performance in withstand voltage, switching characteristics, and breakdown resistance as main circuit elements, as well as to the digital circuits which are incorporated in the control unit and are compoased of less number of component parts.

III. STANDARD SPECIFICATION

The standard series of Fuji Electric's power transistorized uninterruptible power supply units is shown in *Table 1.* Among those units, the three-phase units are selected to illustrate the external view of a 100 kVA unit in *Fig. 2* and to list the standard specifications of Models 73 and 83 (AC input, floating charge type) in *Table 2.*

IV. CIRCUIT CONFIGURATION

Fig. 3 reveals the block diagram of the main circuit.

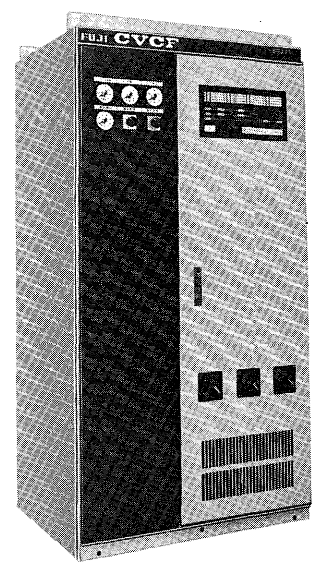


Fig. 2 External view of 3-phase 100 kVA uninterruptible power supply

The main circuit is composed of the DC power section providing with storage battery recharging function and the inverter section which converts DC into AC. An uninterruptible power supply system can be composed merely by connecting a storage battery. AC input is inverted into required voltage under insulated conditions through the input transformer and changed into smoothed DC through the thyristor rectifier and the DC filter. This DC power supply section provides with voltage and current characteristics necessary for recharging the storage battery. The inverter section incorporates the two three-phase bridge inverters provided with power transistors and these inverters are operated with 30° of phase difference between using the two transformer (deltaster connected transformer and delta-zigzag connected transformer), waveform as shown in *Fig. 4* is obtained. Harmonic wave with the minimum order contained in this waveform is 11th. A reversed L-shaped L-C filter is used for an AC filter for rectifying the waveform. Inductance utilizes leakage from transformers.

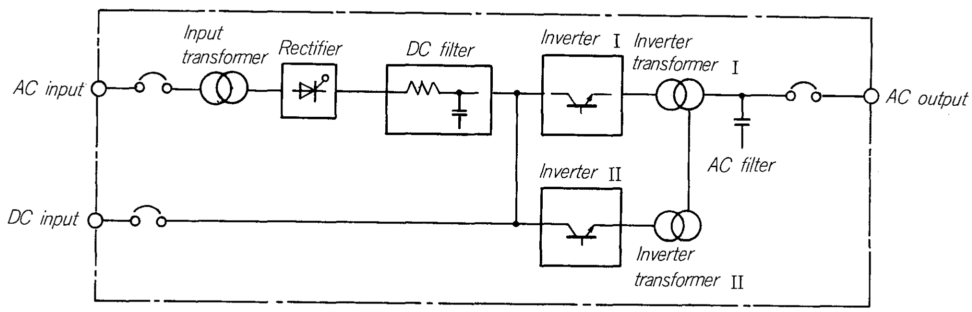


Fig. 3 Block diagram of main circuit

Table 2 Standard specifications of Fuji transistorized three-phase uninterruptible power supply

	Model	73/20	73/30	73/40	73/50	73/75	73/100	73/150	83/200	83/200	83/250	83/300
Input	Voltage	200V ± 10%										
	Frequency	50 Hz or 60 Hz ±5%										
	Nos. of phases and wires	3-phase, 3-wire										
Output requirements	Rated capacity (kVA/kW)	26/16	30/24	40/32	50/40	75/60	100/80	125/100	150/120	200/160	250/200	300/240
	Voltage	200, 208V (50 Hz or 60 Hz), 220V (50 Hz only), and 230V (60 Hz only)										
	Frequency	50 Hz or 60 Hz										
	No. of phases and wires	3-phase, 3-wire or 3-phase, 4-wire										
	Load factor	0.7 (delay) ~ 1.0 (rating: 0.8)										
	Voltage accuracy (when set)	±1.5%										
	Transient voltage fluctuation Conditions:	±8% Conditions: 1) When load is rapidly changed by 30% 2) When input voltage is rapidly changed within the range of ±1.0% 3) When commercial power fails and recovers 4) When one unit is selectively interrupted (only parallel operation mode) 5) When changing over from ups to bypass or vice versa										
	Response time	100ms										
	Harmonic distortion	5% (square mean value of total harmonic at 100% of linearity load) 3% (max. value of single harmonic at 100% of linearity load) 10% (square mean value of total harmonic at 50% of rectifier load and 50% of linearity load)										
	Interphase voltage unbalance	±3% (when difference between max. and min. phase currents is 30%)										
	Frequency accuracy	±0.1% (for internal oscillation)										
	External sync. range	±1%										
	Overload resistance	120% 1 min or 150% 10 sec (guaranteed operation value)										
	Overcurrent limits	150% (when overcurrent exceeds 150%, the current drooping characteristic functions to limit the overcurrent 150% or less)										
	Output phase difference	120° ± 1° (for balanced load) or 120° ± 3° (for 30% unbalanced load)										
	Voltage adjustable range	±5% (for rated load)										
Other items	Ambient temperature	−10 ~ +40°C (for operation), −20 ~ +70°C (for storage)										
	Relative humidity	30 ~ 95%										
	Noise	60 ~ 70 dB										
	Dielectric strength	2000V, 1 min (main circuit)										
	Dielectric resistance	3 Mohm or more (at 500V meggar)										

V. INNOVATIVE TECHNOLOGY APPLIED FOR POWER TRANSISTORIZED POWER SUPPLY UNITS

1. Transistor stack

Transistor stack is one of the most important devices in the power supply units and so high reliability as well as excellent maintainability are required. Therefore, one unit is composed of the circuit structure as shown in *Fig. 5*. The unit structure including a cooling units as shown in *Fig. 6* is adopted. This unit is composed of transistors, diodes, snubber, and base driving circuit, while the transistors are parallel-connected to increase current capacity. The snub-

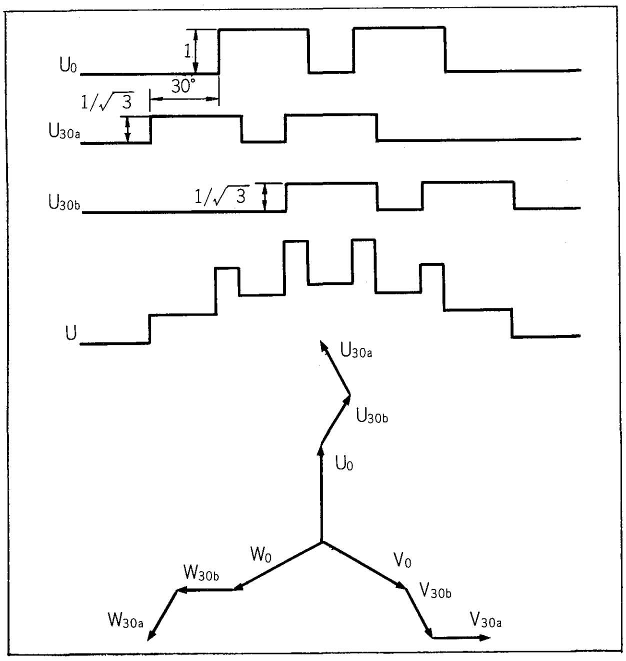


Fig. 4 Waveform of multi-connection and vector diagram

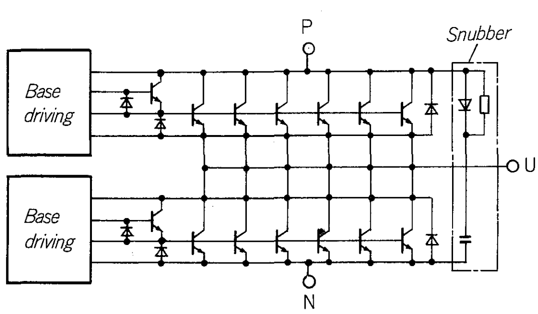


Fig. 5 Connection diagram of transistor stack

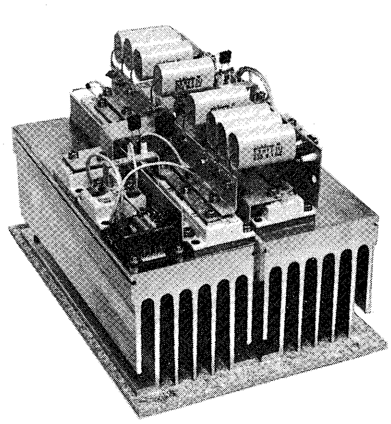


Fig. 6 Exterior view of transistor stack

ber circuit is structured by connecting between the DC power supply P and N a discharge-preventive type circuit composed of resistance, çapacitor, and diodes, because transistors do not require suppression of voltage increasing

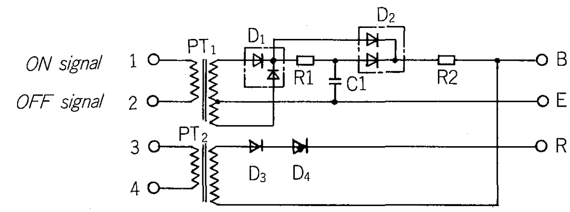


Fig. 7 Base drive circuit

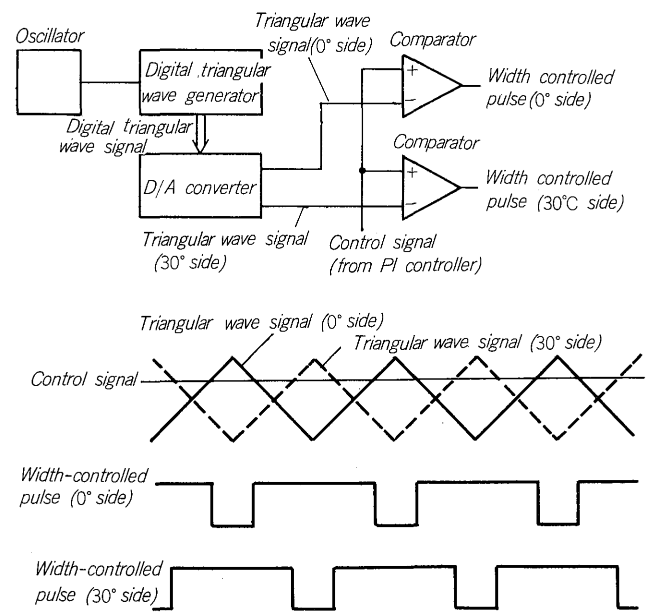


Fig. 8 Phase control circuit

ratio (dv/dt).

2. Base drive circuit

Fig. 7 reveals the connecting diagram of the base drive circuit. The base drive circuit assumes an important function to transmit on/off signals from the control circuit to the main circuit transistor base under the insulated conditions so that high reliability is required for this circuit. In our system, therefore, pulse trnasformer is employed for this purpose. To attain the goal of compact size, a method is employed to smooth the ON signals through a capacitor after transmitting them under harmonic modulation. (Patents applied for)

3. Control circuits

As shown in *Fig. 4,* the two three-phase bridge inverters and the two trnasformers are used for multi-connection in the inverter section. This means that the control circuit requires two phase control circuits which should be equally phase-controlled while keeping 30° of phase difference. To attatin this goal, a method to produce individually two analog triangular waveforms to compare with control signals was conventionally adopted. However, this method

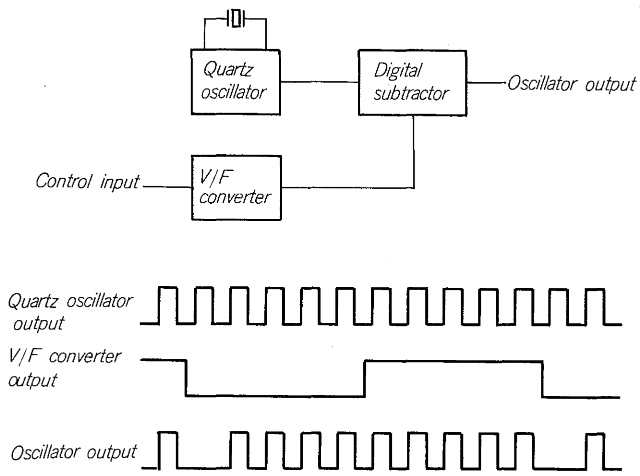


Fig. 9 Construction of oscillator

involves many problems such as excessive number of component parts, needs of regulation, and other points related to quality and reliability. To solve these problems, our device produces two triangular waveforms by using one digital triangular waveform and a D/A converter and produces width-controlled pulse signal through comparing them with the control signal, thereby being a phase control method. (Patents applied for)

In addition, the power supply unit is designed to enable automatic testing through employing digital circuits for timer circuit and pulse distribution circuit and adopting clock-synchronizing structure for the main part of the control circuit.

To facilitate commercial synchronous operation or parallel operation, further improvement was conducted as to the oscillator which was less stable due to the structure with so many component parts. A method as shown in *Fig. 9* is employed in which quartz oscillator and V/F converter are used to compose a simple digital circuit to effect subtraction and to conduct V/F conversion with accuracy and stability. (Patents applied for)

4. Protection

Since transistors are less in instantaneous overcurrent resistance than thyristors, they are hardly protected by using fuses. However, transistors possess high switching speed and enable to effect high-speed interruption. Thus, the Fuji three-phase uninterruptible power supply units are provided with the following three types of protective methods:

The first method is to detect load current at the time of overload and to use PI regulator to limit the output current of the inverter. Should overcurrent occur, it is limited to 150 % of the rated value for the first 10 seconds and to 120 % thereafter, and should such overload continue for more than 1 minute, the load is automatically transferred from ups to bypass circuit without any interruption.

The second method is an instantaneous current limiting method. This is the function to protect the transistors from starting rush current of transformer and rectifiers or from rapid overcurrent when load is short-circuited. In case load current is instantaneously increased, if current limitation by using PI regulator is employed in the control circuit, the transistors will be broken within the control response time. Therefore, this method is to detect instantaneous current value of a transistor by using Hall CT with excellent response which has been developed in advance, to narrow the pulse width without time delay, and to limit the current value lower than a fixed value.

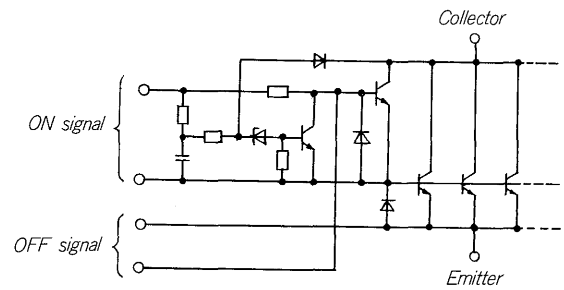


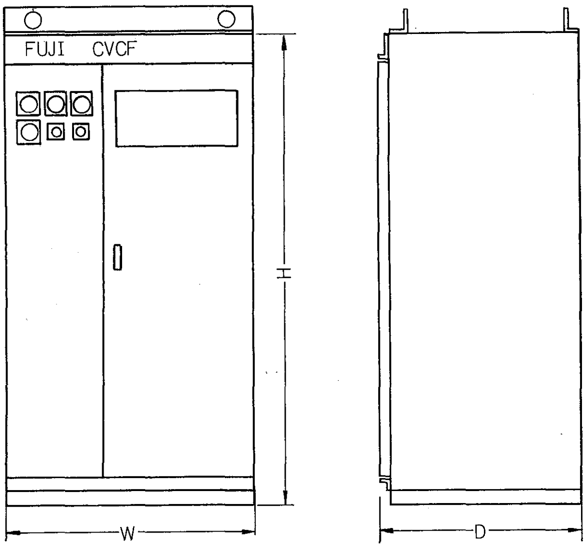
Fig. 10 Overcurrent protective circuit

The third method is a protective one to be used when a transistors which are parallel-connected with the broken one may be protected from further breakdown. By incorporating a transistor overcurrent protective circuit in the base circuit as shown in *Fig. 10*, the transistor can be immediately interrupted, should overcurrent occur in that transistor, and the control circuit detects this functioning of the overcurrent protective circuit to suspend the operation of the inverter. This is based on a method to interrupt the base current when the control circuit detects the fact that collector-to-emitter voltage has exceeded a prefixed value as a result of increased current through the transistor. (Patents applied for)

VI. EXTERNAL VIEW AND STRUCTURE

Fig. 11 shows the external dimensions of the power supply units. In designing this series of power supply units, consideration was given to compact size and reduced depth to minimize installation space and to the structure which allows maintenance and inspection service from the front side. In addition, for the purpose of minimizing restoration time after a trouble occurs, the device interior contains functionally classified units which will facilittate detection of troubled unit. A graphic panel is provided as a standard unit to display trouble causes, operation sequence, and operating conditions.

In the transistor stack which is the main part of the device, transistors and DC filter capacitor units are alternately arranged because the transistors are subjected to high-speed switching operation, thereby being protected from influences of wiring inductance. Since the transistor stack is compact and lightweight as shown in *Fig. 6*, main-



Output capacity (kVA)	Width W (mm)	Depth D (mm)	Height H (mm)	Remarks
20	1000	800	1950	
30	1000	800	1950	
40	1000	800	1950	
50	1000	800	1950	
75	1000	800	1950	
100	1000	800	1950	
125	1400	1000	1950	
150	1400	1000	1950	
200	2400	800	1950	Input transformer is not included
250	2400	800	1950	
300	2400	800	1950	

Fig. 11 External dimensions

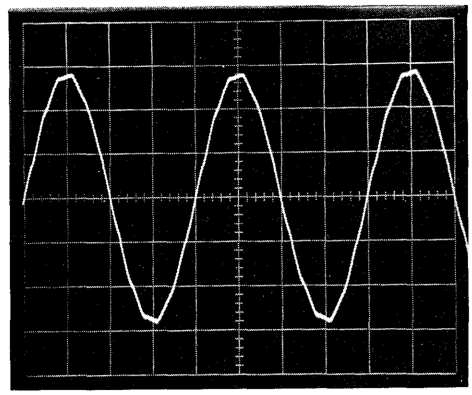
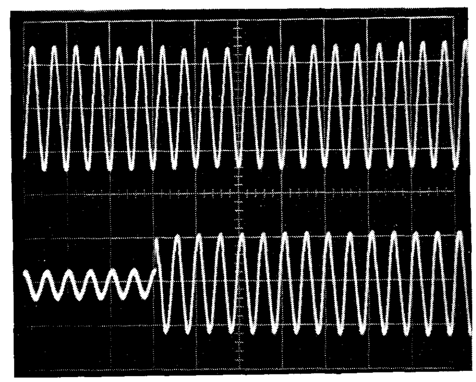


Fig. 12 Waveform of output voltage



Upper: Output voltage waveform (200V/*div*)
Lower : Output current waveform (100A/*div*)

Fig. 13 Waveform of output voltage at 30 % sudden change in load

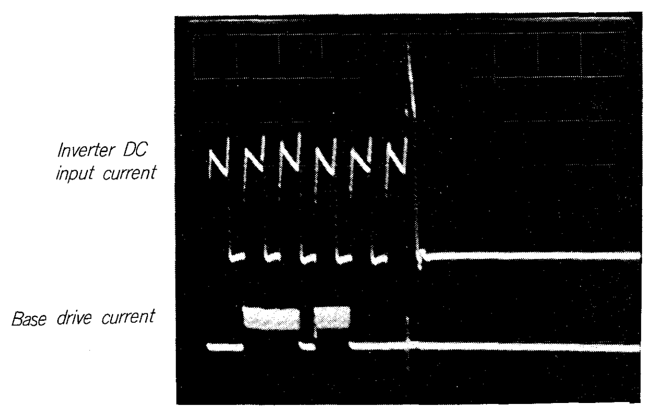


Fig. 14 Waveform of output voltage and output current at the short circuit test of the load

tainability has been substantially enhanced when compared with conventional thyristor tray types.

The control printed circuit board is composed of a large-sized one so that each one board for changer and for inverter may suffice for the minimum system. To ensure excellent workability and maintainability, connectors are employed to connect printed circuit boards with each other or with external units.

In addition to the above-mentioned consideration to minimize size and weight, thin plate structure is adopted to further reduce the weight, and component parts are ideally arranged by considering thermal problems which may occur as a result of the reduced size.

VII. TEST RESULTS

The standard specifications of the device are shown in *Table 2*. To supplement them, test results on some typical performance are outlined hereunder.

1. Output voltage waveforms

Fig. 12 reveals the output voltage waveforms of the inverter. By employing the multi-connecting system as shown in *Fig. 4* the inverter section is designed to be free from low-order harmonics, while the filters are designed by taking rectifying load into account. As a result, the waveform distortion ratio fully meets the standard specification value (5 % or less for linearity load and 10 % or less for 50 % rectifying load).

2. Output voltage variation when load rapidly changes

Fig. 13 shows an oscillogram of output voltage at the time of changing load from 10 % to 40 %. Since the

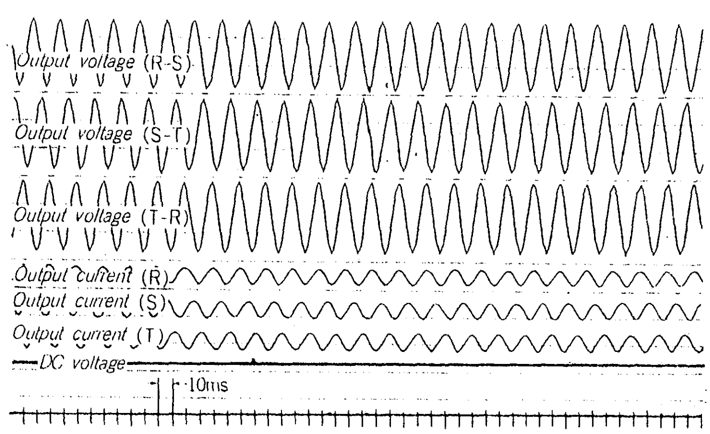


Fig. 15 Waveform of DC current when overcurrent protective circuit functions

variation in the output voltage is approximately −6 % when changing load rapidly from 10 % to 40 %, the standard specification value is fully satisfied. About 60 ms of setting time indicates excellent response.

3. Load short-circuiting test

Fig. 14 reveals an oscillogram of load short-circuiting test conducted by using a fuse. It is found from this figure that when load is short-circuited, the instantaneous current limiting circuit starts functioning to limit the output current to a prefixed value or less, and that after the fuse is blown, steady-state operation is resumed immediately, without showing any disturbance in the output voltage.

4. Test to confirm functioning of overcurrent protective circuit

Whether or not the overcurrent protective circuit functions correctly was tested by using a conductor to short-circuit between collector and emitter of one of the two sets of transistors series-connected to DC power source in a three-phase inverter. *Fig. 15* reveals the base drive current waveform of the transistor in which overcurrent flowed and the DC input current waveform of the inverter. When a base signal is supplied to one transistor while the other is short-circuited by using a conductor, excessive current flows through the former transistor. The protective circuit starts functioning of the protective circuit thereafter suspends the operation of the inverter.

VIII. CONCLUSION

We have introduced the outlines of the three-phase commercial-frequency versions among Fuji Electric's standard series of power-transistorized uninterruptible power supply units. Fuji Electric has supplied the international markets with loads of this type of devices including thyristor types. Since it is expected that computer-aided equipment will be used more and more popularly, it is certain that demands will be further increased for smaller and higher-reliability uninterruptible power supply units. As described above, Fuji Electric's power transistorized uninterruptible power supply units are provided with lots of technological features in which favorable characteristics of the power transistors are fully utilized. We feel certain that ours are the power supply units fully matched to the current market needs thanks to the above-mentioned features as well as the substantially compact size and excellently high reliability.

We continue to make strenuous efforts in offering power supply units with high cost-permormance and enhanced reliability through fully utilizing a great variety of capacity series in the Fuji power transistors so that our customers throughout the world may be satisfied with them.