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NEW SERIES UPSS WITH IGBTS

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1. FOREWORD

The trend toward miniaturization and upgrading the performance of electronic computer hardware has been prevalent along with the improvement of micro electronic computer technology in recent years. The range of computer application systems has shown a rapid expansion covering from large systems such as the on-line system used by financial institutions to small systems such as OA, LAN and so on. It is well known that these computers are sensitive to power source voltage fluctuation (voltage decrease, momentary power failure) causing erroneous operation and even halting operation. In order to prevent such mishaps, it has been common to install a UPS.

Recently, the main target of development technology on the UPS concerns application of high frequency switching technology. This technology realizes compactness light weight, AC input harmonic current reduction, output voltage distortion reduction under capacitor input type rectifier loads and so on. The UPS application technology has been gradually extended to cover from small to large capacity UPS, and also to follow the trend toward electric current capacity increase and improvement of performance of the high-speed switching devices such as MOSFET or IGBT.

The authors have developed a compact, lightweight and high performance three-phase UPS useing IGBTs and also completed a line-up and integration of the 75kVA-200kVA UPS models. This paper introduces its technical specifications, circuit configurations, hardware structures and test results.

2. TECHNICAL SPECIFICATIONS

Table 1 shows the specifications of the UPS. This model is equipped with standard specifications to adjust fluctuation of both output voltage waveform distortion influenced by the rectifier load and unbalance ratio among the output line-to-line voltages. Also, the specifications adopt a function to suppress AC input harmonic current and AC input capacity in order to make it possible to connect the UPS to small capacity electric power supply lines without trouble. The operating method of this UPS makes it possible to reliably switch output power supply from the inverter side to the by-pass line side without interruption at the occurrence of output overcurrent, or inverter failure. (Reversal transfer type UPS without power supply interruption).

3. CIRCUIT CONFIGURATION AND THE CONSTITUENT TECHNOLOGY

This chapter explains the configuration and operation of the main circuit employed in the UPS as well as the constituent technology for mainly IGBT application and the related control technology.

(1) Main circuit configuration and function

Figure 1 shows an overall configuration diagram of the 200kVA UPS. The main circuit consists of high power factor converter, PWM inverter, inverter transformer, AC filters, AC switch and so on. Both the high power factor converter and the PWM inverter use the same units and the capacity of a single unit is 100kVA. Further, via a reactor on the converter side and a transformer on the inverter side, two units of 100kVA each are connected in parallel to obtain 200kVA.

Under the afore-said configuration, batteries are connected within the internal DC voltage lines to realize noninterruption at the AC output section.

The high power factor converter operates to convert AC input voltage up to higher DC voltage than its peak value, and the converter also functions to control AC input current waveform into a sine wave which is free from excessive distortion in order to charge the batteries and supply power to the PWM inverter.

PWM inverter produces output AC voltage on a width modulated pulse array without lower harmonic component from the DC voltage. The AC voltage on the pulse array is isolated and converted by the inverter transformer, is shaped into a sine wave voltage having low distortion via the AC filter made of leakage inductance of the inverter transformer and capacitors, then passes through the AC switch to become an AC output.

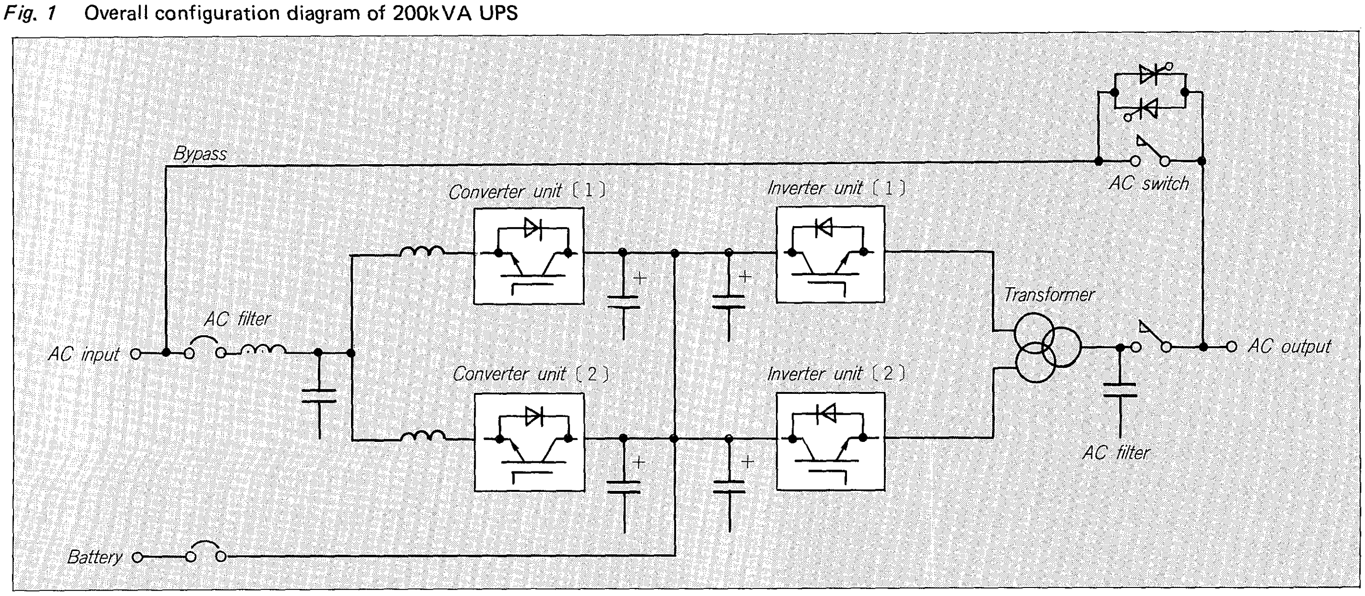
(2) IGBT stack

IGBT stack requires high reliability and maintainability since it is the most important element in UPS device structure. *Figure 2* shows IGBT stack circuit consisting of IGBT, gate drive circuit, snubber circuits, electrolytic capacitors

Table 1 Specification of IGBT type UPS

Specification	Model	077/75	077/100	077/150	077/200
Input	Voltage	200V ± 10%			
	Frequency	50Hz or 60Hz ± 5%			
	Number of phase and wires	3-phase 3-wire system			
	Capacity [kVA]	83	110	165	220
	Input	200V ± 10% 3-phase 3-wire system (isolated neutral system)			
Output conditions	Rated capacity [kVA]	75	100	150	200
	Voltage	200V			
	Frequency	50Hz or 60Hz			
	Number of phase and wires	3-phase 3-wire system			
	Load power factor	0.7 (lagging) ~ 1.0 rating 0.8 ~ 0.9 (lagging)			
	Voltage accuracy	±1.5%			
	Transient voltage change	① 100% sudden load change: ±5% ② Input voltage ±10% sudden change: ±5% ③ Mains power interruption and recovery: ±5% ④ UPS bypass switching: ±8%			
	Response time	10ms			
	Waveform THD	Under 5% (100% linear load) Under 8% (100% non-linear load)			
	Voltage unbalance between phases	At a 100% unbalance load: 3%			
	Frequency accuracy	±0.1% (for internal oscillation)			
	External synchronous area	±1% at rated frequency			
	Overload capacity	120% 1 min., 150% 10 sec.			
	Output voltage adjustment range	±5%			
Battery	Back-up time	10 min. at a 100% load, 30 min. at a 50% load (ambient temperature +25°C)			
	Cell number	12V x 30 set (x 2)	12V x 30 set (x 3)	12V x 30 set (x 4)	12V x 30 set (x 5)
Other	Noise (average)	60dB (A)		65dB (A)	
	Ambient Temp.	–10 ~ +40°C (recommendation level +18 ~ +27°C)			
	Relative humidity	30 ~ 90%			
	Dielectric strength	2,000V 1 min. (main circuit)			
	Insulation resistance	over 3MΩ			

Fig. 1 Overall configuration diagram of 200kVA UPS



and fuses. *Figure 3* shows an independent structure of the single stack including an exclusive-use cooling fin. The single stack constitutes a corresponding single phase of both the high power factor converter and the PWM inverter, thus three stacks constitute a single unit of these converters.

Figure 4 shows the IGBT module (2MBI150-060, V_{CE} = 600V, I_C = 150A) containing two elements manufactured by Fuji Electric employed in the UPS. *Figure 5* shows the equivalent circuit of the IGBT module. Six IGBT modules are connected in parallel to increase current capacity on the single stack. Following are two items of special consideration for securing constant flow of electric current at the IGBT module regardless of steady or switching transient time periods.

First, we made a simple selection of the IGBT modules with regard to the $V_{CE(sat)}$ characteristics.

Second, we adopted a unit structure of new design that connects electrolytic capacitors directly to the conductor which connects the IGBT modules in parallel, as shown in *Fig. 3*, in order to equalize and also minimize the inductance of wirings from electrolytic capacitors to each IGBT module.

As shown in *Fig. 4*, the stack structure also makes it possible to miniaturize the snubber circuit contained within a plastic case and installed directly to each IGBT module.

(3) Gate drive circuit

Figure 6 shows an IGBT gate drive circuit diagram. High reliability is a must for the circuit since it plays an important role to isolate and transfer signals dispatched from the control circuit against the IGBT modules in the main circuit portion of UPS. Pulse transformers having intrinsic noise suppression characteristics are used for the isolation system and also, we employed a method to modulate signal from the control circuit using high frequency and transmit the signal with isolation using two pulse transformers, then demodulate it at the secondary side in order to achieve further miniaturization of the device. In order to secure higher reliability, we also adopt a built-in overcurrent protection circuit of IGBT which shuts off the gate signal as soon as $V_{CE(sat)}$ goes beyond the specified value on state of IGBT and transmits the overcurrent detection signal to the control circuit.

(4) High power factor converter control circuit

As mentioned above, the high factor converter functions to convert AC current into DC current while applying its high factor function to control AC input current into a sine wave which is free from distortion. *Figure 7* shows the converter control block diagram. The items of detection from the main circuit and AC input voltage, AC input currents and DC output voltage. AC input voltages are detected in referential sine waveforms, and command values of the converter input currents are created through multiplication of the referential sine waveforms by AVR output to maintain constant DC output voltage. The system performs instantaneous waveform control to make the detected values of actual AC input currents follow the command values of the converter input currents, and the referential sine waveforms are individually added to the

Fig. 2 Connection diagram of IGBT stack

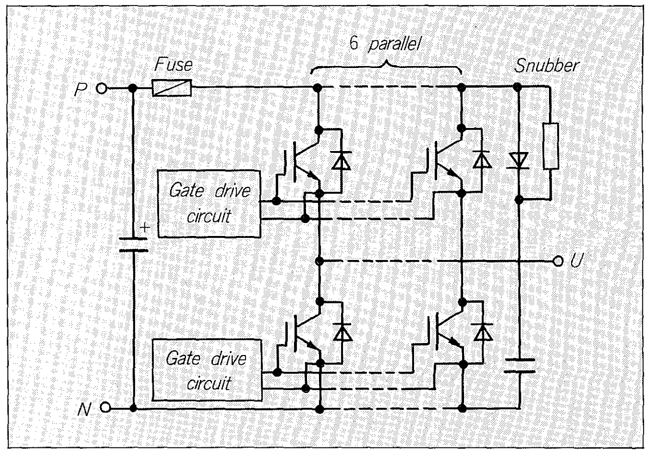


Fig. 3 Outline view of IGBT stack

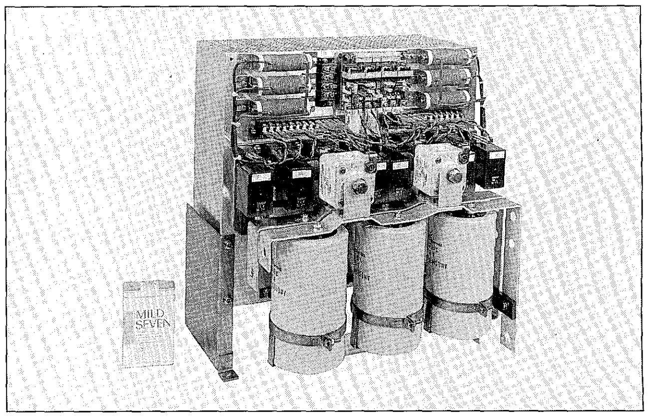


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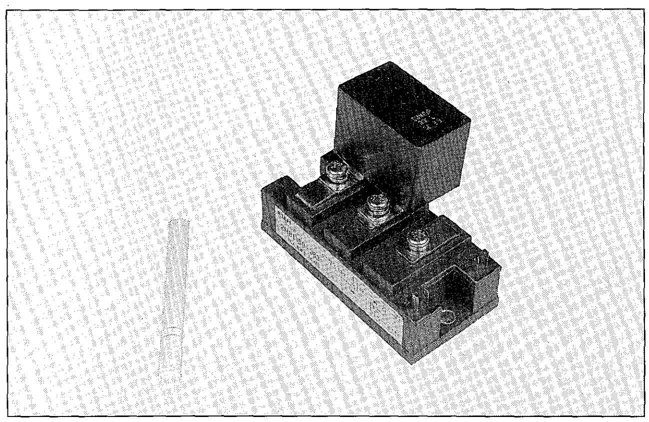
Fig. 4 IGBT module and its snubber



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control signals of each corresponding phase in order to minimize control deviation and achieve higher performance. Triangular form is adopted for carrier wave of the PWM and the frequency is set at approximately 8 kHz.

(5) PWM inverter control circuit

Figure 8 shows the modulation method employed for PWM inverter. It uses trapezoidal wave as signal wave of phase voltage and triangular wave as carrier wave. The line-to-line voltage is the difference (ex. U-V) between the two trapezoidal waves (U and V) which has 120 degrees of phase difference between them and the fundamental sine wave component constitutes the main factor. The following expression shows the relation among V_1, E_d and λ.

$$V_1 = \lambda \times E_d/\sqrt{2} \quad \cdots\cdots (1)$$

Where

V_1 : Effective value of fundamental component included in line-to-line voltage (U-V)

E_d : DC voltage

λ : Control ratio (amplitude ratio between signal wave and carrier wave)

The modulation method as above increases ratio of voltage utilization in comparison with the traditional three phase PWM method for sine wave – triangular wave. Since carrier frequency is set for high frequency at the same approximately 8 kHz as the converter, sine wave with small distortion is obtained only by attaching a small AC filter.

Output voltage control of the PWM inverter is performed using both the traditional average voltage control method and the novel instantaneous waveform control method. *Figure 9* shows the inverter control block diagram. The average voltage control method automatically adjusts amplitude of trapezoidal signal wave to maintain constant rectifying average of AC output voltage. In the instantaneous waveform control method, command values of the two line-to-line voltages, V*(R-S), V*(T-S), composed from the trapezoidal waves are compared with the instantaneous values of the corresponding actually detected values, V(R-S), V(T-S), then, after passing through controllers, instantaneous wave control signals V'(R-S), V'(T-S) are created. The signal calculation circuit creates the three individual phase voltage control signals, V_R, V_S, V_T, corresponding to each arm of the inverter necessary to activate IGBT of the inverter from the two line-to-line voltage control signals. *Fig. 10* shows an operation vector diagram of the signal calculation circuit. The following is the expression of the above.

$$V_R = V'(R\text{-}S) - 1/2\ V'(T\text{-}S) \quad \cdots\cdots (2)$$
$$V_S = V'(T\text{-}S) - 1/2\ V'(R\text{-}S) \quad \cdots\cdots (3)$$
$$V_T = -1/2\ [V'(R\text{-}S) + V'(T\text{-}S)] \quad \cdots\cdots (4)$$

Figure 10 shows a balanced wave of three phase that is calculated using the above expressions and it composes signals corresponding to each individual arm of the inverter. Given the control operation as above, it enables performing the instantaneous waveform control to obtain the three line-to-line voltages which are free from excessive distortion and without mutual interference by way of the two line-to-line voltage detections.

Fig. 5 Equivalent circuit of IGBT module

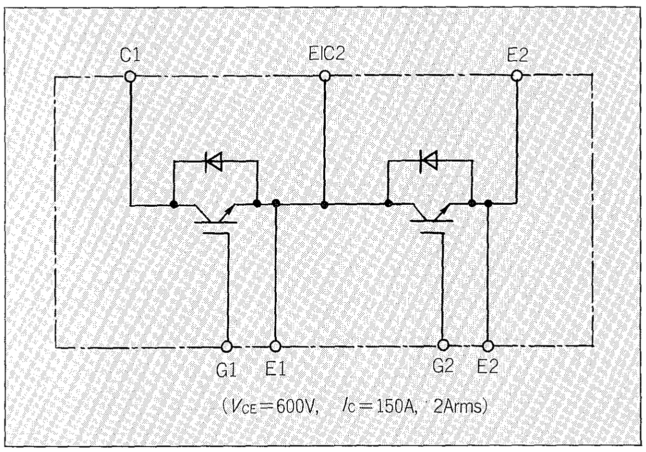


Fig. 6 IGBT's gate drive circuit diagram

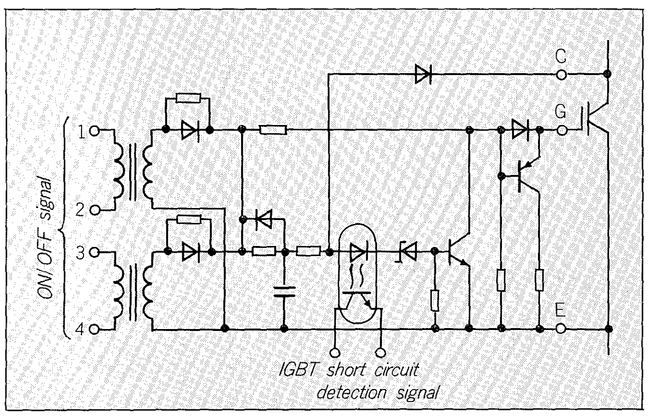


Fig. 7 Converter control block diagram

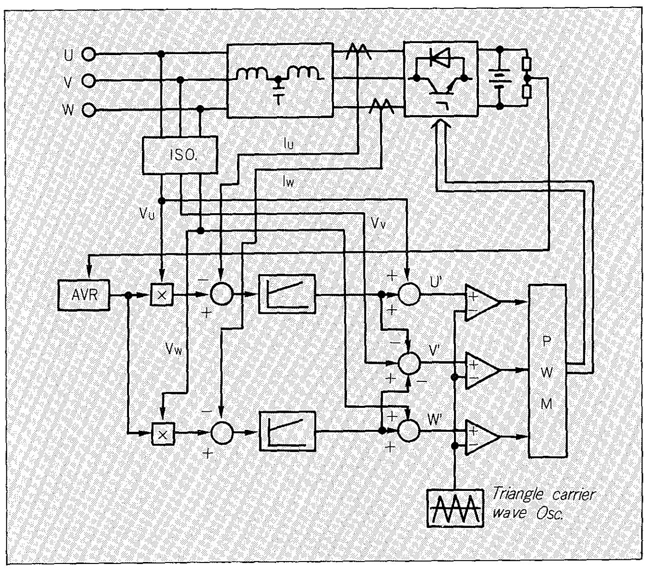


Fig. 8 Principle diagram of PWM

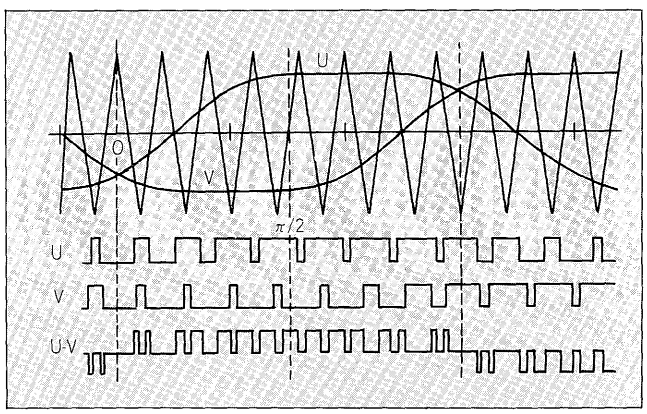


Fig. 9 Inverter control block diagram

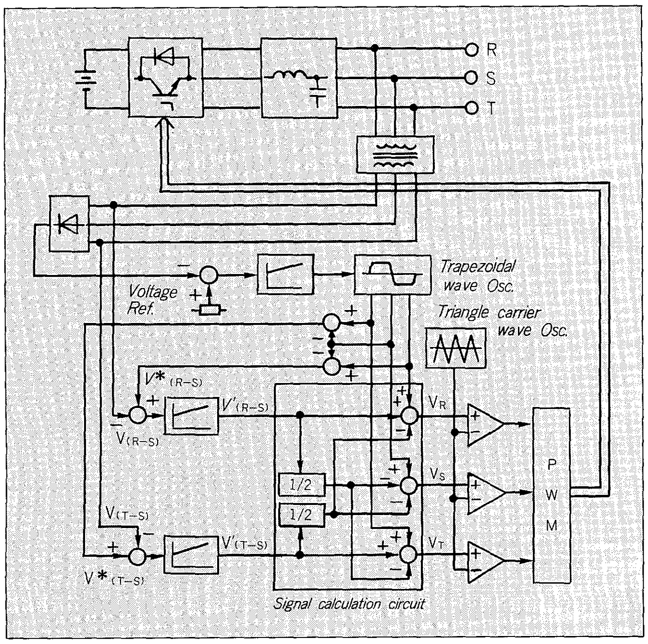
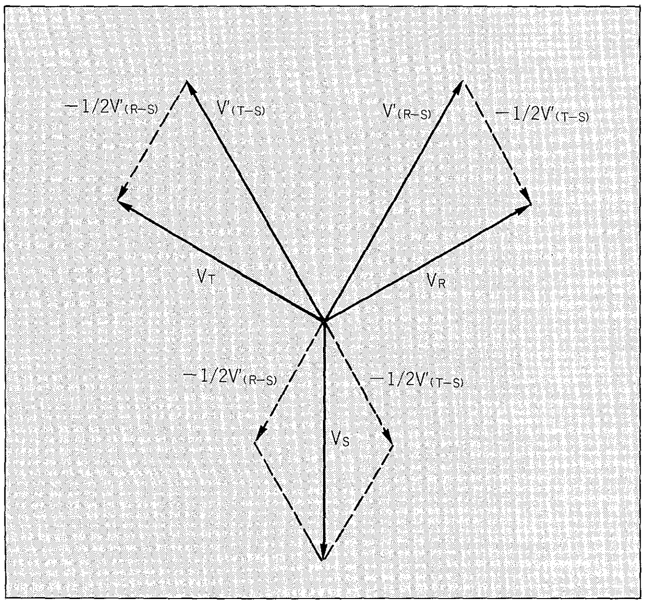


Fig. 10 Operation vector diagram



(6) Display interface

The 200kVA UPS is equipped with an operation display panel at the front of the main cubicle in order to improve the operability and maintainability. The display panel comprises integrated sheet form keyboard, LCD with back light and LED controlled by microcomputer.

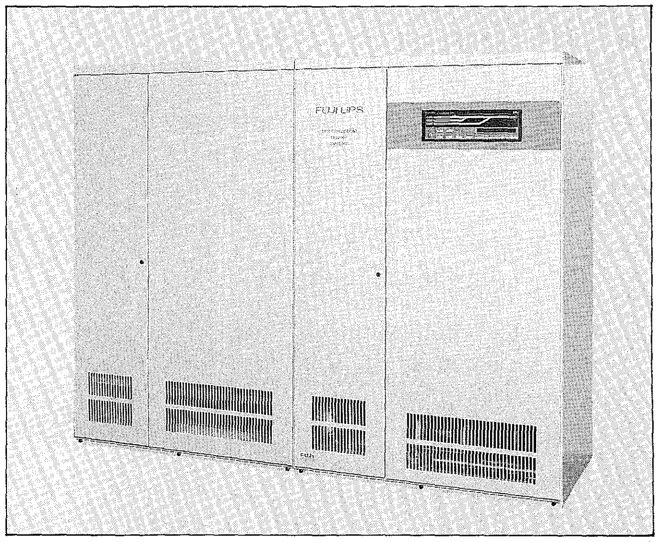
Following are the contents of the display:

① Status indication
– Graphical indication of operation status

② Measurement value indication
– Voltage, current and frequency of all the sections

③ Operation handling guidance

Fig. 11 Outline view of 200kVA IGBT UPS



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④ Troubleshooting guidance

⑤ Maintenance guidance

⑥ Recording – Number of battery driven operations and total operation time period of the UPS

The UPS is also equipped with external interfaces such as RS-232C port and T link port for Fuji programmable controller. The interfaces make it possible to flexibly cope with requirements from external control such as remote control etc., and also allow connection to personal computers.

4. OUTLINE AND INTERNAL STRUCTURE

Figure 11 shows an outline view of the UPS (200kVA model). Following are the dimensions and weight (without battery).

Dimensions:
[1,100(W) x 750(D) x 1,700(H)mm] x 2 cubicles
Approx. weight: 2,000kg

Item / Model	Dimension $W \times D \times H$ (mm)	Weight (kg)
77/75	900 x 750 x 1,750 1 cubicle	1,000
77/100	1,100 x 750 x 1,750 1 cubicle	1,200
77/150	900 x 750 x 1,750 2 cubicles	1,700
77/200	1,100 x 750 x 1,750 2 cubicles	2,000

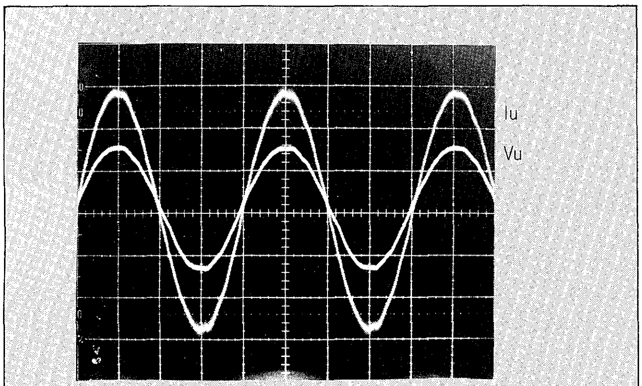
The equipment design employs a two-cubicle configuration to minimize single cubicle dimensions so as to make it possible to transport them through office entrance and/or use an elevator.

5. TEST RESULTS

(1) AC input current waveform

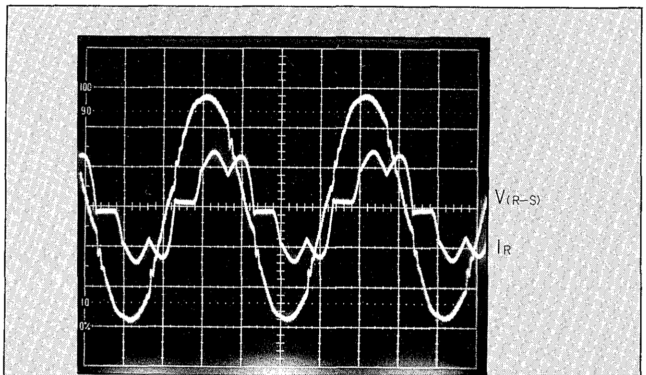
Figure 12 shows AC input current waveform of the 200kVA UPS. As afore-mentioned the waveform composes

Fig. 12 Input current waveform



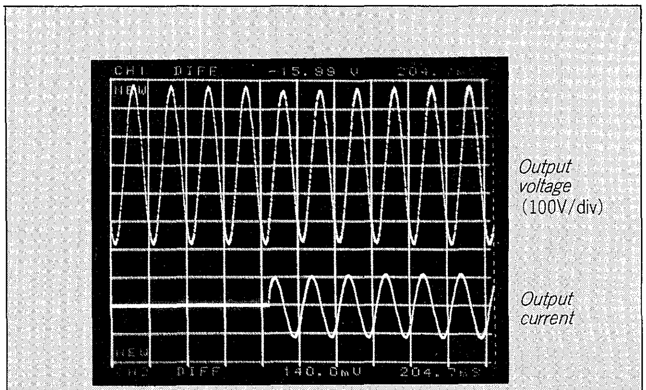
(Iu : 500A/div, 2.4% THD)

Fig. 13 Output voltage waveform



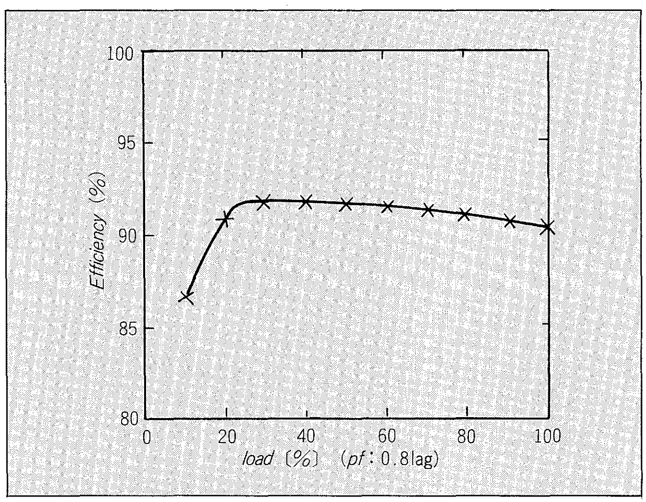
($V_{(R-S)}$: 100V/div, 3.9% THD)
(I_R : 500A/div, rectifier load)

Fig. 14 Oscillogram of sudden load change



(*laod change* : 0→100%)

Fig. 15 Efficiency characteristics



a sine wave which is free from excessive distortion and the power factor is high since the equipment employs high power factor converter. The measurement test results are satisfactory with regard to the specification showing a current wave distortion factor of 2.4% and power factor of 0.99.

(2) AC output voltage waveform

Figure 13 shows AC output voltage waveform of the 200kVA UPS. As afore-mentioned the waveform distortion factor is little deteriorated even when connected to the rectifier load including a lot of harmonic components since the attached AC filter is miniaturized, and also, the instantaneous waveform controlled HF PWM inverter is installed. The measurement test results show voltage waveform distortion factor of 3.9% evidencing significant improvement in comparison with the traditional method.

(3) Output voltage fluctuation occurring at sudden change of the load

Figure 14 shows an oscillogram obtained at the occurrence of sudden change with 100% load. The test results show by the same reason as above that quantity of fluctuation of the output voltage is as small as 5-6% during the time passage of both load input and load shutoff and the specifications are well satisfied. The test results also evidenced an excellent response, that is, the settling time period taken for the voltage to be stabilized at the stationary value is only for transient of approx. 4-5 cycles.

(4) Conversion efficiency

Figure 15 shows an efficiency curve in relation to load ratio for the 200kVA UPS. The test results show a conversion efficiency ratio of 90.1% with the rated loading and also show more than 90.0% of the range of load changes extending from the ratio of 15% up to 100% of the load. The test results evidence that the 200kVA UPS is a practical use equipment.

6. CONCLUSION

The paper introduces the new three phase UPS (Uninterruptible Power System) utilizing high frequency switching technology together with the IGBT (Insulated Gate Bipolar·Transistor) as switching devices. The UPS realized a compact, lightweight, low acoustic noise and high performance design to enable it to be installed at any space (not necessarily an exclusive power source room) and also to be connected to small capacity electric supply lines while achieving higher power factor of AC input current and reduction of harmonic components. The target of new UPS development is to accomplish a complete system applicable to a 100% rectifying load without capacity reduction so as to enable connecting with loads such as various computers and computer related hardware.

The foreseeable power source environment of computer related hardware shows a trend toward continuous deterioration, since there are many scenes where a number of computer related hardware users share the same electric supply line as already seen at new intelligent buildings. In order to solve the problem, it is essential to develop and proceed with effective countermeasures, for example, where all the customers individually install and use their own UPS and so forth. We are proud of our new IGBT type UPS which may be installed at any available space and is supplied with complete user-friendly features, and hope you will permit us to render our utmost effort in future for further development of advanced UPS that our customers would be ready and willing to use.