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TRANSISTORIZED CVCF INVERTER

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I. FOREWORD

The growth of data processing systems has lead to the widespread use of thyristor inverters to supply stable power in bank on-line, traffic control systems, industrial plants, and so on. Fuji thyristor inverters have been delivered to numerous fields and excellent operating results have been obtained.

Newer computer systems are changing from on-line centralized control to functionally dispersed processing by terminal computer, therefore low capacity, high reliability power supplies are demanded.

Moreover, the manufacture of transistorized power supplies up to about 10kVA has been made possible through improved performances and stable supply of power transistors, and since a forced commutation circuit such as that of conventional thyristor system is unnecessary, excellent performances can be obtained in transient characteristics and efficiency.

The 1ϕ 3kVA transistorized CVCF inverter manufactured and delivered by Fuji Electric will be outlined here.

II. FEATURES OF TRANSISTORIZED INVERTER

Power transistors feature higher speed switching than thyristors, turn on and turn off of the element by merely turning the base current on and off, and elimination of the forced quenching circuit. Consequently, they have the following features as equipment:

1) Improved performances by high operating frequency

Since the Fuji Electric inverter employs a pulse width modulation method (PWM method) and its high operating frequency through the use of transistors, the AC filter for sine waveform can be made compact and the output voltage distortion made low.

2) Improved transient characteristic

Since the response speed is fast, stability relative to variation in the power line voltage and load is excellent.

3) Improved reliability through elimination of forced commutation circuit.

The forced commutation circuit is unnecessary in our system and, therefore, there is no commutation failure. Moreover, since there is no loss during commutation, the inverter with high efficiency can be realized.

4) Improved protection function

Unique control circuit concepts make possible an instantaneous limitation of output voltage for overloads, short circuits and surge current, therefore, its stability is excellently improved.

5) Small size, light weight.

Miniaturization of the filter and elimination of the forced commutation circuit allow a reduction of about 60% in volume and weight as compared with conventional thy-

Table 1 Specifications of 3kVA CVCF inverter

Item		Specifications
DC input	Rated voltage	DC 110V
	Voltage variation range	DC 88~143V
AC output	No. of phases	1ϕ
	Rated voltage	AC 100V
	Static voltage regulation	±1.5%
	Rated voltage frequency	50Hz
	Frequency accuracy	50Hz ±2% (asynchronous state)
	Distortion factor	Within 5%
	Capacity	3kVA
	Load power factor	0.8 (lagging) ~ 1.0
	Performance	100% continuous 120% 1 minute 150% momentary
	Dynamic voltage regulation DC input voltage variation (at 100% load) ±10% Load variation ±20%	Within ± 7%
	Load variation ±50% At inverter ↔ utility changing (at 100% load)	Within ±10%
	Response time	Within 5 cycles
Efficiency		80% minimum
Source change-over system	Uninterruptible change between inverter and utility	Automatic: Inverter ↔ utility Manual: Inverter ↔ utility
Others	Ambient conditions Temperature Humidity	 −10 ~ +40°C 30~90%

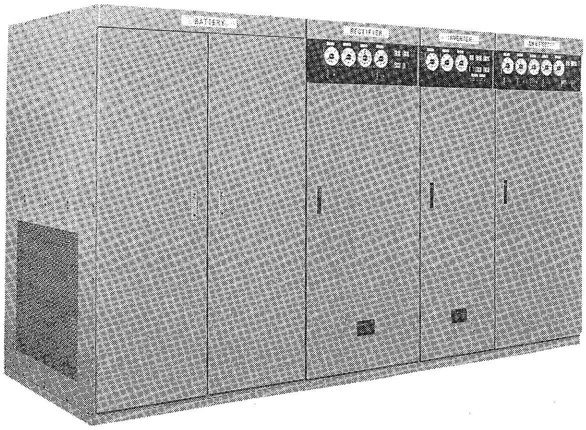


Fig. 1 3kVA uninterruptible power supply

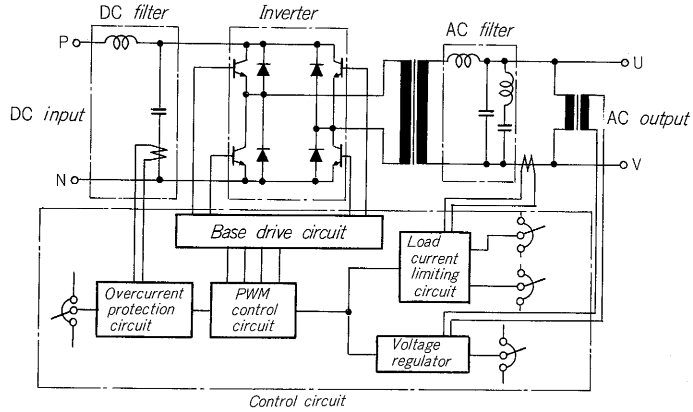


Fig. 3 Schematic diagram of transistorized CVCF inverter

ristor inverters. Furthermore, since there is no forced commutation circuit to act as a source of noise, the inverter is very silent.

III. RATINGS AND SPECIFICATIONS

The 1ϕ 3kVA inverter was manufactured and delivered as one link-in an uninterruptible power supply including battery charger, battery, and feeder panel. Its exterior view is shown in *Fig. 1*, and the ratings and specifications of the inverter are given in *Table 1*.

IV. CIRCUIT CONSTRUCTION AND OPERATION

The main circuit construction of this equipment is illustrated in *Fig. 2*, and the connection diagram of the inverter section is given in *Fig. 3*. Circuit operation and control functions will be described below.

1. Modulation Method

This inverter employs PWM system with high operating frequency utilizing the previously mentioned features of the power transistor.

Various modulation method can be considered as PWM systems, but the "sine wave - triangular wave PWM system" is employed in this inverter.

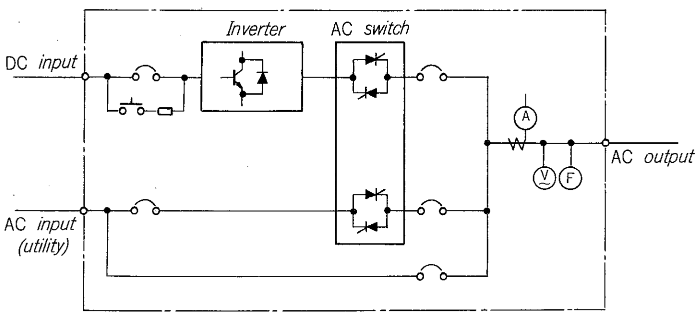


Fig. 2 Skeleton diagram of transistorized CVCF inverter

Time chart of sine wave-triangle wave PWM system is shown in *Fig. 4*.

The carrier frequency (triangular wave: *fc*) and signal frequency (sine wave: *fs*) ratio (*fc*/*fs*) is called the modulation frequency ratio.

Since, theoretically, the output harmonic components are concentrated near the 2*fc*/*fs* component in case of the modulation method illustrated in *Fig. 4*, the AC filter is made smaller as the modulation ratio is selected higher.

In this inverter, a modulation frequency ratio of 15 has been selected because of the characteristics of the transistors, etc.

Since two signals (sine waves), having 180° phase difference but same amplitude, are compared with the carrier signal (triangular wave) and an output is obtained by combining the results of comparison of both signals, the input voltage waveform at the AC filter is a signal modulated by 30 times of the signal frequency.

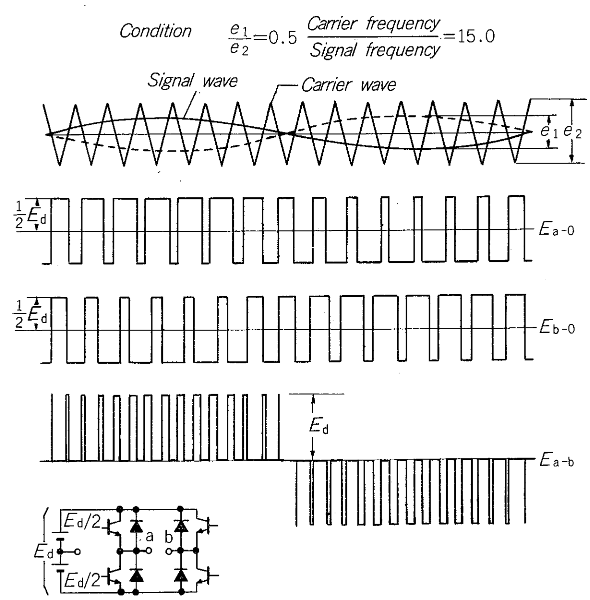


Fig. 4 Time chart of sine wave - triangle wave PWM system

The output voltage is controlled by making the amplitude of the carrier wave constant and changing the amplitude of the two signal waves simultaneously.

2. Inverter Main Circuit

The inverter main circuit consists of a DC input filter, inverter, isolation transformer, and AC filter.

The inverter switching elements are high capacity power transistors, and the inverter section has been simplified and the AC filter made small through the adoption of the PWM method with high carrier frequency previously described.

3. Constant Voltage Control Circuit

Output constant voltage control is achieved by means of a PI regulator, the same as conventional inverters. However, the response time of the control system has been improved substantially over that of the conventional thyristor CVCF inverter through the adoption of the PWM method with high carrier frequency and a small AC filter.

4. Current Control Circuit

As mentioned in section **III**, since the specifications relative to overloading of this equipment are 1 minute at 120% overload and instantaneous stop at 150% overload, to satisfy these specifications, a double overcurrent control and protection system consisting of an overload current limiting circuit (PI controller) set to 120% current and an instantaneous trip circuit that immediately stops the inverter at 150% current are provided.

The functions of the former are sufficient for the purpose of preventing burning caused by an overcurrent at the overload. However, the latter is applicable for the purpose of protecting the inverter against, for example, shorting at load circuit and other sudden overcurrents to which the PI controller cannot respond.

When the latter has been operated, the inverter is stopped and the supply of power to the load is also halted. In the past, the inverter remained in this state, but since this is undesirable for power supply equipment that requires high reliability, this inverter is immediately stopped and power supply is automatically changed over to the utility when the load current reaches 150% of the rated current to cope with overloads at the high power capacity of the utility. Then the inverter is restarted and synchronous operation with utility is performed. When the load has returned to normal (load of 100% or less) and the inverter is synchronized with the utility, the load is automatically changed from the utility to the inverter to assure high reliable power supply.

5. Protection Circuit

In addition to the double overcurrent protection system described in para. **4**, a transistor overcurrent protection circuit that detects the current of the smoothing capacitor of the DC circuit and turns all the power transistors off when an overcurrent has flowed in the power transistors is provided to prevent destruction of the power transistors by an overcurrent.

Generally, overcurrent destruction by rapid fuse is impossible because the instantaneous overcurrent endurance of power transistors is smaller than that of thyristors, therefore, a protection circuit with instantaneous response function, such as this circuit, is essential.

The circuit employed in this inverter has a detection time delay of 5μs or less, and protects the power transistors against overcurrents to which the previously described load current limiting circuit cannot response, such as at shorting of the load, etc., and also against sudden overcurrents such as isolation transformer layer shorts and direct shorting of the inverter output.

Moreover, when this protection circuit has operated, the inverter is stopped and remains stopped until the necessary action has been taken from the outside. Furthermore, in this case, the load is automatically changed over to the utility without interruption.

6. Uninterruptible Change Circuit between Inverter and Utility

As described, since the utility can be used as the back-up power supply when the inverter is stopped, a highly reliable power supply system can be established.

Normally, the load is supplied by inverters operating at the same phase and same frequency with the utility. When the utility fails, the inverters are operated at a constant frequency by an oscillator inside the inverter. In addition to the automatic changing function described in paras. **4** and **5**, a manual changing circuit is provided to stop the inverter for maintenance, inspection, etc. This circuit is capable of changing from the inverter to the utility and from the utility to the inverter. Synchronization of the inverter and utility is a essential condition in this case also.

7. Control Circuit Power Supply

This equipment does not use an expensive DC-DC converter, but performs rectification of the utility and the inverter output through isolation transformers and makes the rectified voltage of the utility somewhat high. Therefore, practical functions are obtained by adopting a system in which control circuit power is normally supplied from the utility and is supplied from the output of the inverter itself when a power interruption occurs at the utility.

V. CONSTRUCTION

The trouble recovery time of this equipment has been speeded up by unitizing to each function and the difficulty of maintenance and inspection caused by miniaturization have been solved by constructing it so that all inspections can be performed from the front.

The inverter section is a main section of the equipment and its one-arm bridge (consisting of power transistor, fast recovery diode, RC snubber, and base drive circuit) is concentrated on a tray system to shorten the wiring and permit direct connection between parts, considering the influence of the inductance of the power line to high speed switching, and since it can be pulled out from the front of the equipment, maintenance and inspection are simple. (*Fig. 5*)

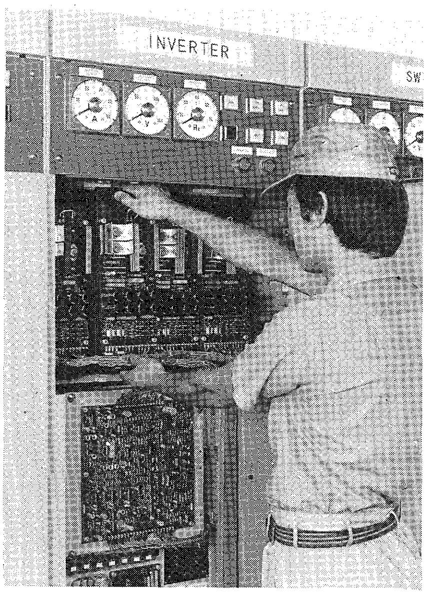


Fig. 5 Interior view of 3kVA CVCF inverter

The following considerations have been paid from the standpoint of reliability in the important control circuits.

(1) Circuits have been made all solid-state and the number of parts reduced.

(2) The PWM with high carrier frequency control circuit and synchronizing circuit to utility are concentrated on two high density jumbo printed circuit boards to reduce the connecting parts.

(3) Pressure contact connectors have been avoided and a screw system employed to assure positive contact.

(4) The use of jumbo printed circuit boards is accompanied by a large number of solder connections, and since the failure rate cannot be ignored, redundancy is provided at connections by using all through holes.

Moreover, since the two printed circuit boards are mounted back to back by a door type mount, adjustment, maintenance, and inspection are simple.

VI. CHARACTERISTICS

The superiority of the following characteristics of this inverter over those of the conventional thyristorized CVCF inverter has been proven.

(1) Equipment efficiency of 80% or greater is secured under the rated input and output conditions. This is an improvement of several percent over that of the conventional thyristor system.

(2) The variation width and response time for transient voltage variations at sudden load changes are smaller than those of the conventional thyristor system, therefore, the supply of higher quality power is possible.

(3) The inverter output voltage waveform is visually excellent, and the required distortion factor of 5% maximum is amply satisfied.

As described above, the transistorized CVCF inverter is backed by a equipment having numerous features superior to the conventional thyristorized CVCF from the standpoints of performances, reliability, small size and light weight.

The test results of the various characteristics are given below.

1) Summary of characteristics

The test results of the various characteristics are compared with the characteristics of a typical thyristorized inverter in *Table 2.*

2) Output voltage waveform

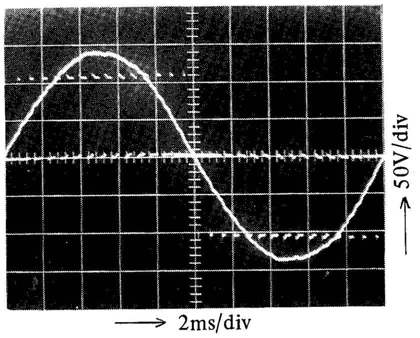
A photograph of the output voltage waveform of this inverter is given in *Fig. 6*. *Fig. 6*(a) is a photograph of the output voltage waveform at no load and *Fig. 6*(b) is a photograph of the output voltage waveform at the rated load.

3) Oscillogram at sudden load change

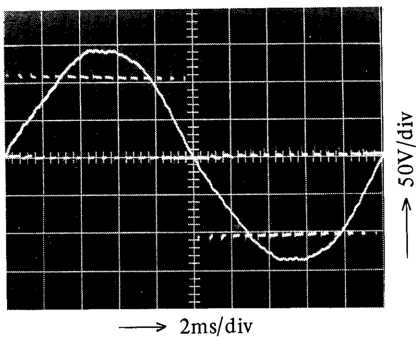
Fig. 7 is an oscillogram at sudden load change of this inverter. *Fig. 7*(a) is the oscillogram at 0% ↔ 50% sudden load change and *Fig. 7*(b) is the oscillogram at 0% ↔ 100%

Table 2 Characteristics of transistorized CVCF inverter

Characteristic items		Transistorized CVCF inverter	Thyristorized CVCF inverter
Static voltage regulation		±1.0% max	±2.0% max
Dynamic voltage regulation	At 0% ↔ 50% sudden load change (load power factor 0.8, rated input)	+6.9%, −5.8% (response time within 1 cycle)	±10% max (response time within 4~5 cycles)
	At ±10% sudden input change (load power factor 0.8, rated load)	+5.6%, −4.5% (response time within 1 cycle)	±10% max (response time 4~5 cycles)
	At manual change from utility to inverter (rated input and output)	−3% (response time within 1 cycle)	±10% max (response time 4~5 cycles)
Equipment efficiency (at rated input and output)		81%	75%
Distortion factor of output voltage		4.1% max	5% max



(a) Voltage waveform at no load



(b) Voltage waveform at rated load

Fig. 6 Output voltage waveforms

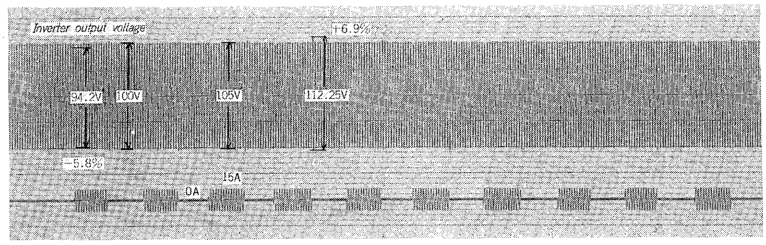
sudden load change.

VII. CONCLUSION

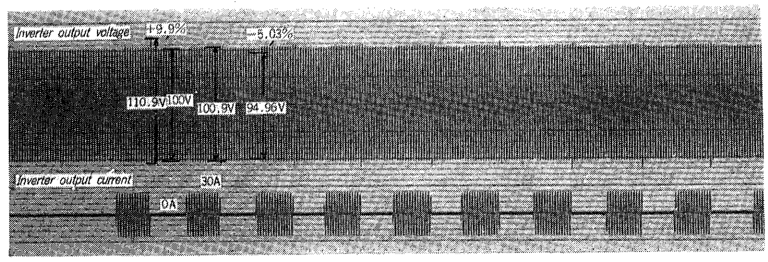
An outline of the inverter employing power transistors is introduced in this article.

As previously mentioned, the demand for stable uninterruptible power supplies will steadily increase in the future and reliability of the entire system will be demanded, and this role will become more important.

The field of applications of power transistors will expand with advances and cost reduction in power transistor manufacturing technology, and we will utilize our past experience and make efforts to manufacture more economical and reliable power supply equipment.



(a) At 0%↔50% sudden load change



(b) At 0%↔100% sudden load change

Fig. 7 Transient response of 3kVA CVCF inverter