UDC 621. 311. 6 : 621. 314. 572

# HIGH RELIABILITY UNINTERRUPTED STATIC POWER SUPPLY SYSTEM FOR ON-LINE DATA PROCESSING SYSTEM

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## I. INTRODUCTION

In the last few years, reliability and stability have become very important in high speed and expanding data processing systems, especially on-line systems. Therefore, the requirements for reliability and stability have also become more severe in the case of power systems used to operate these data processing systems.

However, in keeping with the development of power thyristors and the elimination of moving parts in various power devices, power systems for computer loads have also been shifting from the former rotational types (M-G sets) to the static types (thyristor inverters).

Recently, a highly reliable parallel redundant type of thyristor inverter was developed jointly by Fujitsu and Fuji Electric and was delivered to the Japan Central Racing Association as the power supply for a FACOM totalizator system. Since this power supply is now operating well, it will be introduced here.

## II. POWER SUPPLY SYSTEM USING THE CVCF INVERTER

Generally, the power supply for data processing systems must have stable voltages and frequencies and be protected against noise and power failures so that the power supply necessary for proper operation of the computer system can be maintained. Since the output characteristics must be Constant Voltage and Constant Frequency, the CVCF power supply is normally used.

The CVCF inverter systems consist of three types classified according to the way in which the system is constructed. Since the reliability and economy of these three types differ considerably, it is necessary to choose among them in accordance with the degree of importance of the work to be done by the computer system.

### 1. Single System

As can be seen in *Fig. 1*, this system supplies power to the computer system by means of a single inverter. The features of the system are simplicity and high economy, but the reliability is not so high since no back-up against failures is provided.

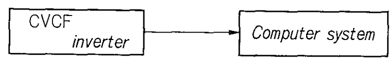


*Fig. 1* Block diagram of single System

### 2. Changeover system

As is evident from *Fig. 2*, this system consists of two inverters for one computer system. One inverter is used to supply power and the other inverter serves as a stand-by. The features of this system are economy since a stand-by device is provided. However, the output is momentarily interrupted when there is a changeover to the stand-by.

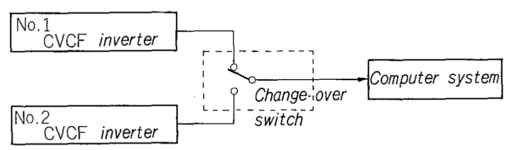


*Fig. 2* Block diagram of changeover system

### 3. Parallel Redundant System

As can be seen from *Fig. 3*, this system consists of several inverters running in parallel for one computer system. The output change when one inverter fails is maintained within the permissible range of the computer and the faulty inverter is automatically dissociated. The reliability of this system is extremely high.

In addition, one inverter is not operated in parallel but is used as a stand-by at the same voltage as the normal load terminal voltage. When a fault occurs in one of the normally operating devices, there is an uninterrupted changeover to the stand-

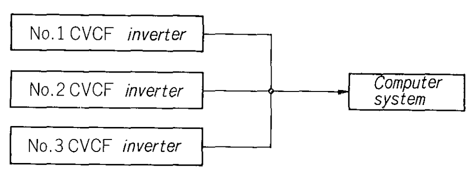


*Fig. 3* Block diagram of parallel redundant system

by device. However, the transient change in the output voltage is rather large because the load change is 100% during changeover (using a thyristor switch).

## III. CONSTRUCTION AND FEATURES OF THE PARALLEL REDUNDANT SYSTEM

### 1. Parallel Redundant System

In order to insure highly reliable power supplies in on-line data processing systems, the parallel redundant system of CVCF inverters has begun to be employed recently.

The main circuits of the inverters consist of thyristors and diodes. There are also control circuits to control the main circuit thyristors. These two components can be combined in the following two ways.

In the first method shown in *Fig. 4*, there is one control circuit for each main circuit, and each inverter including its control system is connected in parallel. The other system is as shown in *Fig. 5*. The main circuits and the control circuits are each connected in parallel in the form of a parallel redundant system.

Both of these systems have advantages and disadvantages. However, Fuji Electric employs the parallel system of two independent inverters since the systems are completely separated, maintenance and checking are easy, expansions are simple and down time is avoided.

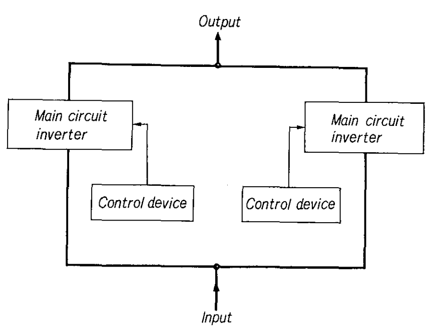


*Fig. 4* Block diagram of individual control system

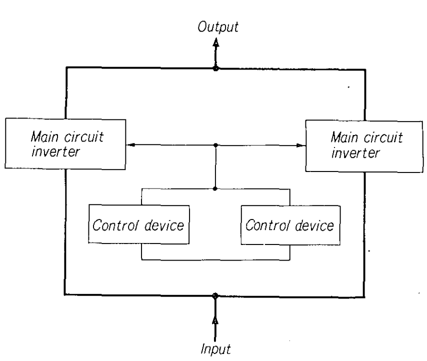


*Fig. 5* Block diagram of parallel control system

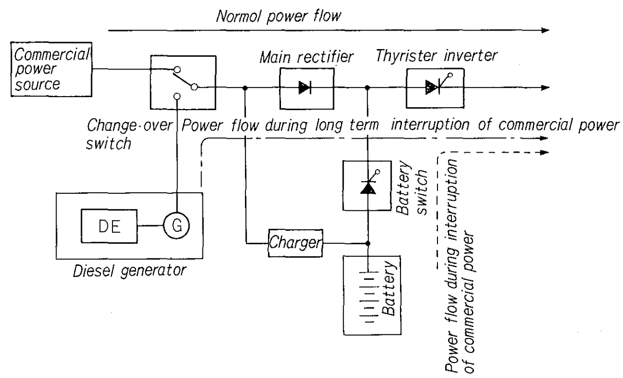


*Fig. 6* Block diagram of uninterruptable power supply system

### 2. Uninterrupted Power Supply System

As can be seen from *Fig. 6*, the uninterrupted power supply system using CVCF inverters converters the AC commercial source into DC power by rectifier and then inverts this DC power into a stable AC power supply by inverters. Batteries or emergency diesel generators are provided in case of interruptions or power failures at commercial source.

Battery charges are not provided in small capacity inverter and in many cases, when a floating charge is in the battery operation is by means of the main rectifier. However, in such cases, the rectifier must be provided with control functions to control the charge and the inverter parts must also be provided with such functions in order to keep the inverter output constant. Therefore, in large capacity equipment, the battery is normally cut off from the inverters, etc. by means of a static battery switch as shown in *Fig. 6* for reasons of economy. The main rectifier is often of the diode type and charging is provided by means of a small capacity battery charger attached separately. Therefore, under normal conditions, the power is supplied via a commercial source, a rectifier and the inverters. When the commercial source fluctuates or is interrupted, the highly sensitive battery switch is closed and power is supplied from the battery.

The battery capacity is generally about 5 minutes under total load operation and it is also economical to provide emergency diesel generators for long term commercial power interruptions.

Commercial power is supplied directly to the computer system in accordance with the degree of importance of the system. The socalled by-pass line is provided in rare cases and a voltage stabilizer is sometimes used depending on the quality of the commercial power supply.

### 3. Main Circuit System

*Fig. 7* shows the skeleton diagram of the main circuit system of a parallel redundant inverter power supply using two inverters, and *Fig. 8* shows the connections of a unit inverter.

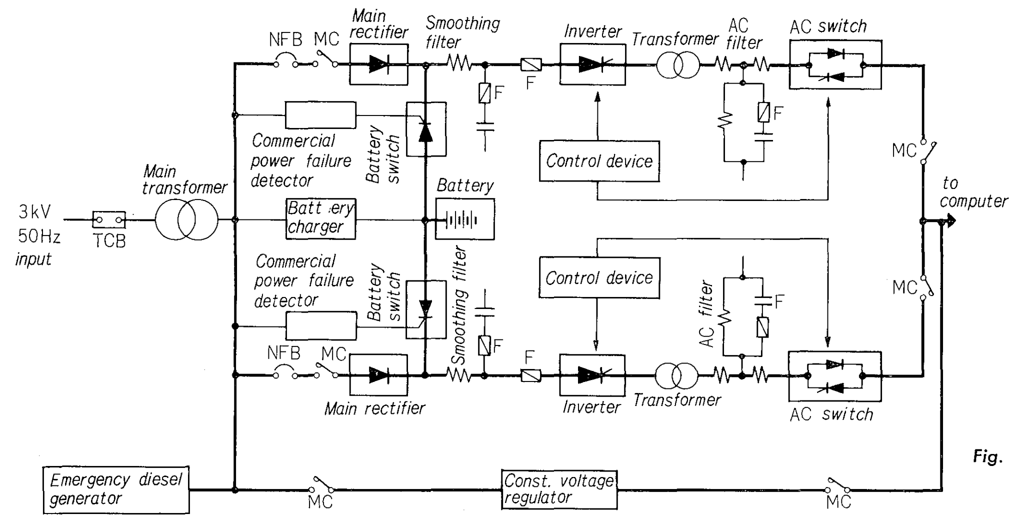


*Fig. 7* **Skeleton diagram of main circuit**

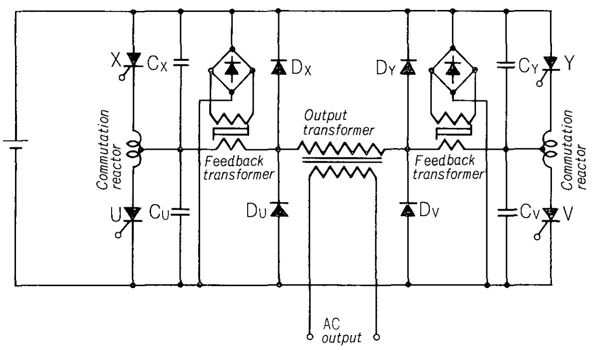


*Fig. 8* **Connection diagram of unit inverter**

A battery is connected via a static battery switch as was described previously in the intermediate DC circuit in order to provide uninterrupted operation. Generally for economy and reliability, one battery is provided in common for two inverters. However, there is a sepatate battery switch for each inverter and there is also one commercial power failure detector to provide signals for each switch in the parallel redundant system.

The smoothing filter in the intermediate DC circuit not only eliminates ripple in the output voltage of the main rectifier but also absorbs load reactive power, provides transient regulation of the inverter output voltage during commercial power failure and recovery, and controls load variations and commercial source variations.

This smoothing capacitor is relatively large and since a large charging current flows via the diode rectifier during starting, special consideration has been given to the rectifier starting method. When the inverter is stopped, the rectifier is completely stopped after the capacitor discharges.

The unit inverter is of the bridge type as can be seen in *Fig. 8*. However, a feedback circuit to minimize commutation loss is included in order to improve the operating efficiency. This bridge type inverter is the basic unit and several of these units connected multiplely to the secondary of the inverter transformer are used in order to minimize the distortion factor of the output voltage wave and reduce the AC filters. The number of these multiple connections is decided by the total capacity of the inverters, at present there are 6 stages in 50 kVA equipment and the output voltage is in the form of 12 pulses. Regulation of the inverter output voltage is performed by controlling the output voltage amplitude of each of the unit inverters.

A filter with a series resonant circuit can be considered as the filter for connection on the inverter output side, but since the inverters are multiple and the distortion is low, the series capacitor at the parallel filter inlet has been eliminated.

The series reactor provided in the filter part has been selected by considering the stability of parallel operation and the stability of the output power during inverter failure.

In the parallel redundant system, more than two inverters which can be operated independently are connected in parallel but since the faulty device must be cut off rapidly when a failure occurs, a high speed switch is required. Fuji Electric employs

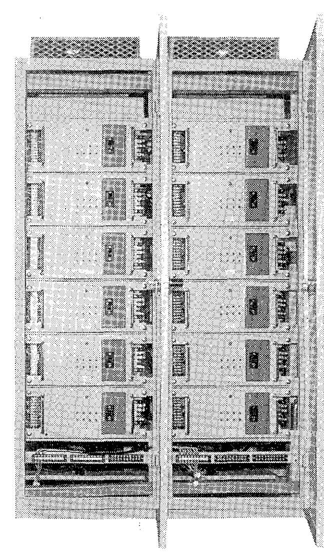

*Fig. 9* **Outer view of inverter cubicle**

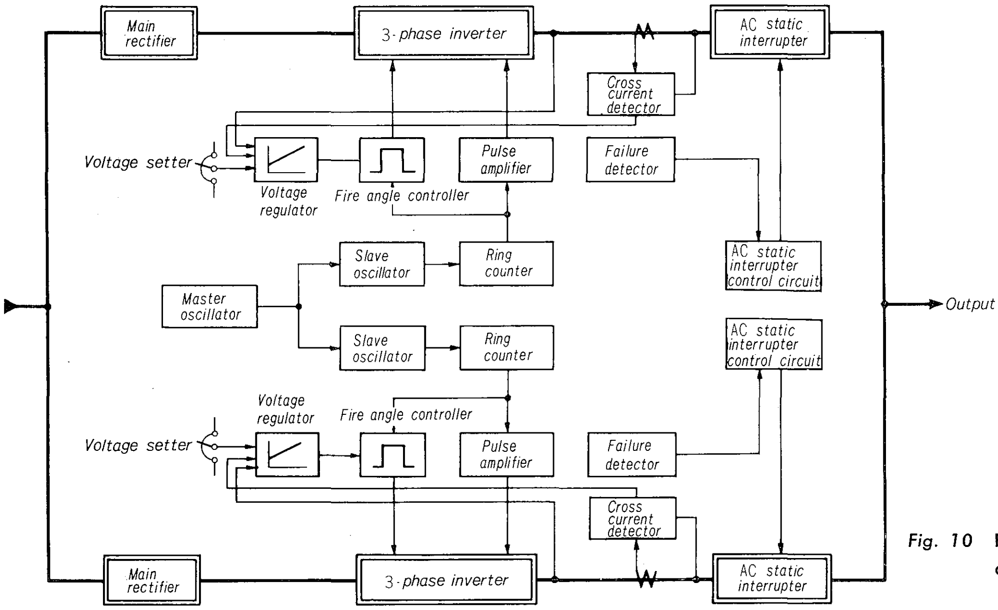


Fig. 10 Block diagram of control circuit

an AC static interrupter using thyristors which is capable of forced commutation. With such an interrupter, dissociation is performed within one half cycle after the failure is detected. The forced commutating circuit is constructed so that peak voltages arising during forced commutating do not reach the load limits.

The inverter section consists of a commutation capacitor, a reactor, a pulse transformer and other auxiliary circuits. These components are accomodated in trays to simplify handling and maintenance and each unit inverter consists of two such trays. *Fig. 9* shows an outer view of the inverter cubicle containing the inverter trays.

The AC switch also contains a forced commutating circuit and each output phase part is accomodated in one tray. The main rectifer, battery switch, etc. consist of individual unit. The semiconductors are cooled by a forced air system.

## 4. Control System

A block diagram of the control system for a 2-unit parallel redundant system is shown in *Fig. 10*. The control circuit consists of a digital control circuit to determine the output frequency by a highly accurate oscillator, an analog control circuit to keep the output voltage constant under normal conditions.

For parallel operation, the output voltages, frequencies, and phase angles of each inverter must match. To match each of the frequencies and phase angles, the digital signals are synchronized mutually. Several methods can be used for this synchronization but Fuji Electric employs a common master oscillator and two slave oscillators which oscillate synchronously with the output pulse of the master oscillator as shown in *Fig. 10* for 2-unit parallel redundant systems. When there is a failure in the master oscillator, operation is automatically switched to individual operation and operation is by means of only the slave oscillators. The phase angles of the output voltages of each inverter are matched by synchronization between each of the pulse distributors.

When three or more units are operated in parallel, there are two master oscillators provided, and when one master oscillator fails, operation is automatically changed over to the stand-by oscillator.

Constant voltage control circuits which keep the output voltage constant are provided for each individual inverter, but since higher accuracy has been achieved by carefully considering the voltage setter and voltage detector, current unbalances and drops in output voltage accuracy are avoided during parallel operation. However, since drift do occur over long periods, the cross current which flows between the two inverters due to the voltage difference is detected and cross current compensation is provided by adding to the input of the voltage control regulator. Since cross current occurs even with very small differences in the output voltages of each inverter, compensation must reduce the cross current

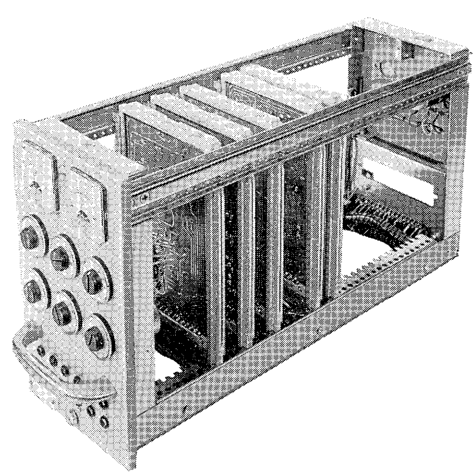

Fig. 11 Outer view of control unit

to zero and the voltage should also be very small. Therefore, there is no loss of constant characteristics at load terminal voltage due to the application of cross current compensation control. When changing over from parallel operation to independent operation, this compensation circuit is simultaneously opened.

The control system is arranged in the form of functional units in order to simplify maintenance and inspection. The tray units can be seen in *Fig. 11.*

### 5. Detection

An important factor in the parallel redundant system is not only that when any fault is detected, the faulty unit is dissociated before the fault in one unit spreads throughout the system, but also that any load terminal voltage fluctuations between the time the fault arises and dissociation be completely eliminated.

Failures in each of the inverters, range from commutation failures to variations in the output voltage. The former are caused by faults in the inverter main circuit section or in the digital control circuit and the latter are due mainly to faults in the parts between the commercial source and the main rectifier, faults in the voltage control circuit due to the analog signal and faults in the static interrupter. Faults in the control system usually range from output voltage fluctuations to commutation failures depending on the magnitude of the fault. Faults in the master oscillator are related to both inverters, but since the equipment is designed so that there will be no influence on the operation of the inverters used for the slave oscillators, only parallel synchronous operation is disturbed. In order to detect all of these faults rapidly, to transmit signals to the static interrupter and to dissociate the faulty unit, the DC current, output voltage and pulse systems are all monitored by highly reliable equipment.

### 6. Features

The Fuji Flectric CVCF inverters have the following features.

(1) High reliability is assured even with individual operation because of the strict reliability control used during manufacture including simple circuit construction, careful selection of parts and long term aging of all parts and devices.
(2) Output voltage fluctuations are as low as 3 to 7% during any disturbance including failures and dissociation.
(3) The faulty unit can be selectively interrupted with accuracy by the unique circuit system in the case of commutation failures or any other failures in any part.
(4) Maintenance and inspection are simple since the important parts of the main circuits and the control circuits are arranged in plug-in type trays. In case of failure, repairs can be made quickly.
(5) Handling is simple since starting and stopping is one-touch, even when performed remotely.
(6) By using many inverters, there is no resonance with the load and a sine wave with low waveform distortion is obtained.
(7) Because of the compact design, the system can be transported in elevators and insallation space is small.
(8) Efficiency is good when compared with the MG and other systems, and the batteries are small.
(9) There are few restrictions on the use of the equipment since noise and vibrations are small.

## IV. TEST RESULTS

The tests results of the parallel redundant system delivered to the Japan Central Racing Association for use in the FACOM totalizator system are outlined below. An outer view of this system is shown in *Fig. 12.*

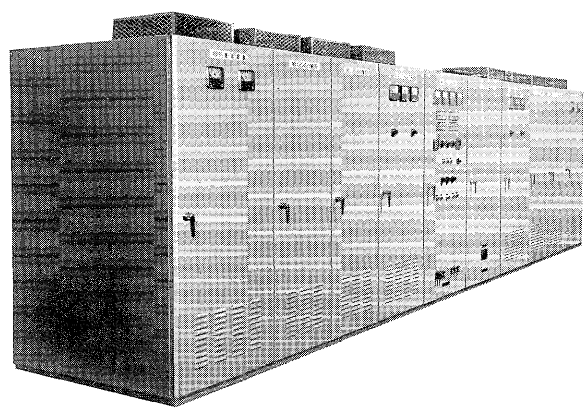

*Fig. 12* Outer view CVCF inverter

### 1. Main Specifications

Input power supply: 3-phase 200 V, 50 Hz and battery
Output capacity: 2×50 kVA
Output voltage: 200 V
Output frequency: 50 Hz
Output phases: 3 phases
Normal output voltage variation: ±1.5%
Normal output frequency variation: ±1%
Transient output voltage variation: ±7%
Transient output frequency variation: ±1%
Voltage unbalance: 4 V (when load unbalance is 20%)
Waveform distortion factor: 10%

### 2. Test Results

1) Static characteristics

*Table 1* shows the normal variation of the output voltage due to various disturbances during parallel operation. The efficiency results were very good: 80.3% during independent operation and 76.3%

**Table 1 Static character of output voltage**

| External interference | Output voltage variation (V) |
|---|---|
| Input voltage variation (180～220 V) | 0.54 |
| Temperature drift (0～40°C) | 0.48 |
| Load change (0～100%) | 1.8 |

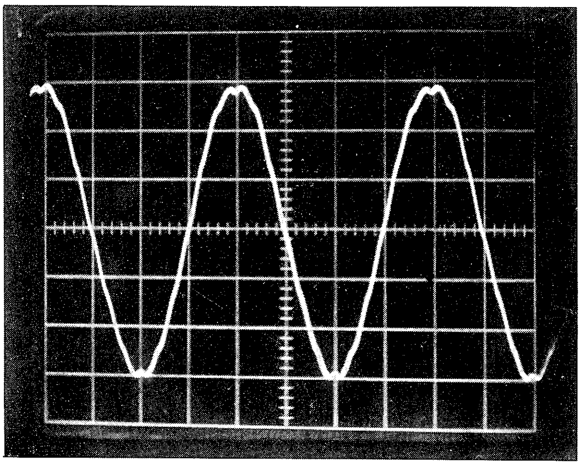

Fig. 13 Output voltage waveform

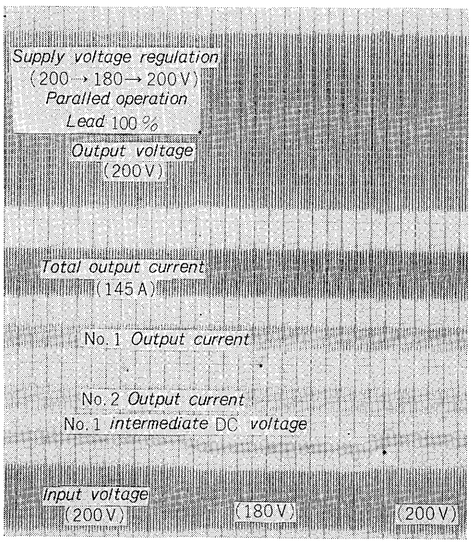


Fig. 14 Oscillogram of output voltage at supply voltage regulation

during parallel operation.

The waveform distortion factor never exceeded 3.5% in all ranges of input and load conditions. The waveform is a shown in *Fig. 13*.

2) Transient characteristics

(1) During rapid changes in input voltage

The transient variation of the output voltage when the input voltage is changed rapidly ±10% was +6.8% and −4.6% during independent operation and +4.3% and −2.6% during parallel operation. In both cases, there was a load of 100% and when the load was decreased, the amount of variation also decreased. *Fig. 14* shows a typical oscillogram.

(2) During rapid load changes

The transient changes of the output voltage when the load was changed rapidly from 10 to 30% and back again were −2.0% and +1.3% during independent operation and −1.6% and +0.8% during parallel operation. During battery operation, they were −0.2% and +0.8%.

(3) During power failure and recovery

The transient variations of the output voltage during commercial power failure and recovery differed depending on the battery charge conditions and the commercial input voltage, but under the most adverse conditions, they were −2.8% and +6.2% during independent operation and −4.8% and +3.8% during parallel operation. The requirements were fulfilled when the power was interrupted continuously for 5 minutes. *Fig. 15* shows a typical oscillogram.

(4) During parallel closing and dissociation

The transient variations in the output voltage for soft parallel closing when there was switching from independent operation to parallel operation and from parallel operation to independent operation was only

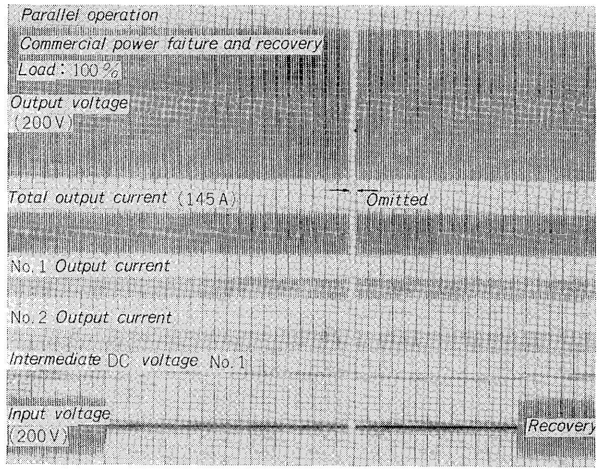


Fig. 15 Oscillogram of output voltage at supply power failure and recovery

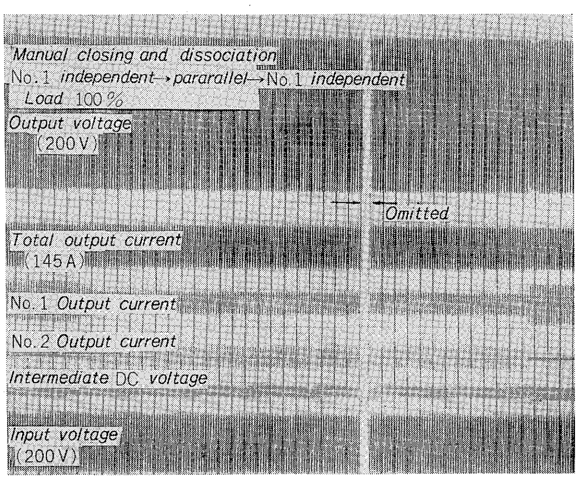


Fig. 16 Oscillogram of output voltage at parallel closing and dissociation

+0.8%. Since the load is rapidly changed from 50 to 100% during dissociation, the variation was slightly larger: −5.5%.

These variations showed almost no change even when the battery was used as the input source. *Fig. 16* shows an oscillogram for parallel closing and dissiociation.

(5) Automatic dissociation during failures

In all cases, the transient variation in the output voltage during automatic dissociation when a fault occurred in one of the inverters during parallel operation was within the required ±7%.

Inverter commutation failures consists of that due to arc-through and that due to misfiring. *Fig. 17* is an oscillogram of commutation failure due to misfiring.

Faults in the voltage control system consist of faults resulting in rapid changes in the inverter output voltage and faults due to slow changes. In both cases the requirements were fulfilled. Typical oscillograms are shown in *Fig. 18* and *19*. *Fig. 20* shows

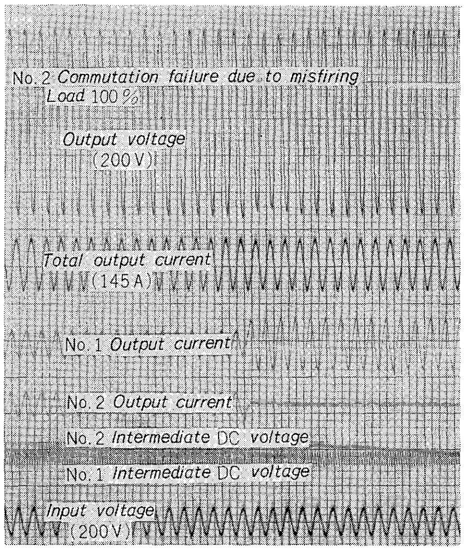


*Fig. 17* **Oscillogram of output voltage at voltage commutation failure**

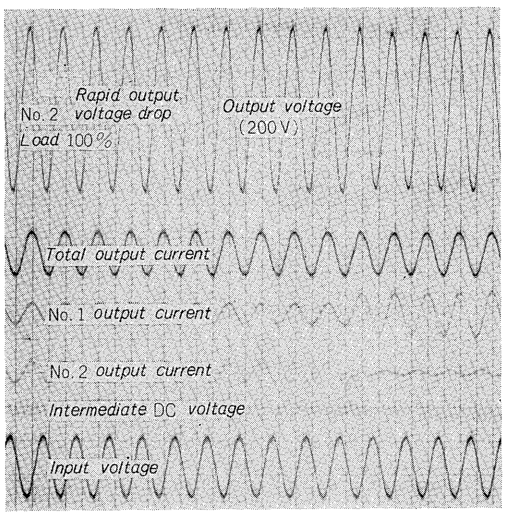


*Fig. 18* **Oscillogram of output voltage at voltage controller failure**

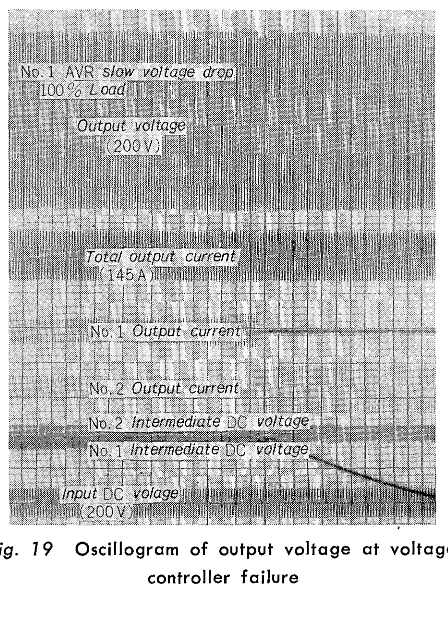


*Fig. 19* **Oscillogram of output voltage at voltage controller failure**

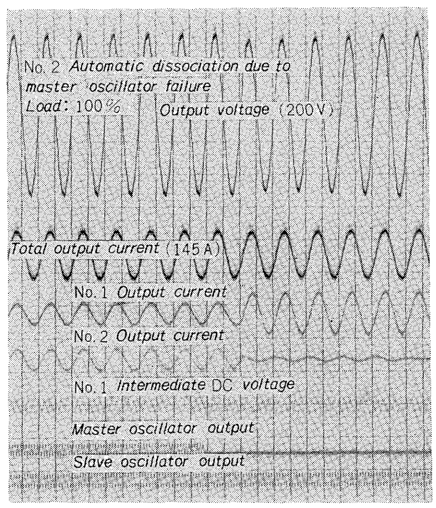


*Fig. 20* **Oscillogram of output voltage at master oscillator failure**

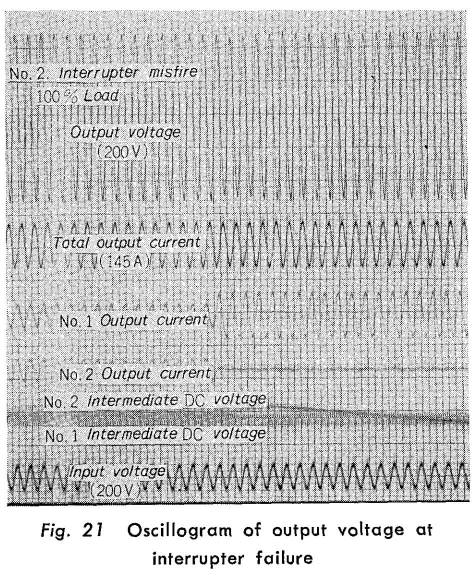


*Fig. 21* **Oscillogram of output voltage at interrupter failure**

an oscillogram obtained during master oscillator failure and *Fig. 21* is an oscillogram for static interrupter failure.

3) Others

Starting time: approx. 8 sec.
Noise: average 74.3 phons
maximum 77.5 phons

## V. STANDARD SERIES

The standard series of the Fuji Electric CVCF inverters for use with computers are shown in *Table 2.*

## VI. CONCLSION

In this age of rapid computerization, extremely high reliability is required for computer power supply systems and technology for providing such reliability is progressing all the time.

The Fuji Electric CVCF inverters are ideal for computers of the 3.5 generation and efforts are continuing to achieve higher reliability, better capabilities and greater compactness and light weight.

Finally, the authors wish to thank those persons in the Japan Central Racing Association and all others who aided with this equipment all the way from the design stage to the final execution.

***Table 2* List of standard inverter series**

| | Item | Performance and specifications |
|---|---|---|
| Input | Rated voltage | 200 V, 400 V, 3.3k V, 6.6 kV |
| | Votlage variation | ±10% |
| | Rated frequency | 50 Hz, 60 Hz |
| | Frequency variation | +1, −2 Hz |
| | No. of phase | 3 |
| Output | Capacity (kVA) | 20, 30, 50, 60 100, 125, 150, 200, 300, 400 |
| | Type of rating | Continuous |
| | No. of phases | 3-phase 3-line or 3-phase 4-line |
| | Rated voltage | 200, 208, 220 V |
| | Nominal voltage accuracy | ±1.5% |
| | Voltage setting range | ±5% |
| | Voltage transient regulation | +10∼−8% (±7% as required) |
| | Rated frequency | 50 Hz, 60 Hz |
| | Frequency accuracy | ±0.5 Hz |
| | Wave form distortion factor | 5% (at rating) |
| | Load power factor | 0.8∼0.95 |
| | Efficiency | 70∼85% (deffers according to capacity) |
| Others | Ambient temperature | 0∼40°C |
| | Ambient humidity | Less than 85% |
| | Noise | Approx. 80 phons |
| | Overcurrent protection | Automatic current limiting system |