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LARGE-SCALE UNINTERRUPTIBLE POWER SYSTEMS

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1. FOREWORD

In a society well connected by information network and proceeding globalization/unprotectism and having advanced social system, functional the newest and the most reliable information are strongly demanded. Computers and other advanced electronic medium are shut-down even if trouble occurs for an instant.

Therefore, an uninterruptible power system (UPS) which supplied AC power continuously regardless of the condition of the power line is indispensable to an information-network society.

Third generation on-line systems are already being introduced in city banks, etc., for example, and on-line systems in the finance and market information field in which large information networks are being built are steadily being globalized. An example of the transition of the on-line system of Japanese city banks is shown in *Table 1*. As information and communication systems become more global, the UPS becomes larger and 2,000 to 20,000kVA computer centers, centered about metropolitan areas in Japan, are being continuously borne.

Backed by its acclaimed semiconductor, quality control, and UPS know-how, Fuji Electric has held a top share of the UPS market for more than 14 years. This article introduces the newest large-scale UPS.

2. FUJI LARGE CAPACITY UPS

Figure 1 shows the Fuji large capacity UPS (100kVA or greater) delivery record. Large capacity systems are increasing favorably, the same as medium and small capacity systems.

Fuji large capacity UPS with 3-phase output and single-phase output are available. Since the demand for 3-phase output is overwhelming, the description is centered about the 3-phase output UPS. This series used the large capacity power transistors which are the pride of Fuji Electric and was available in capacities up to 600kVA for single module. However, a standard series with capacities of up to 1,000kVA has been completed and correspondence to a large-scale UPS has started.

Table 2 lists the standard specifications of the 3-phase output UPS. Especially, 200kVA and greater UPS are standardized with 6.6kV high voltage input. The main

Fig. 1 Fuji UPS delivery record transition (100 kVA or greater)

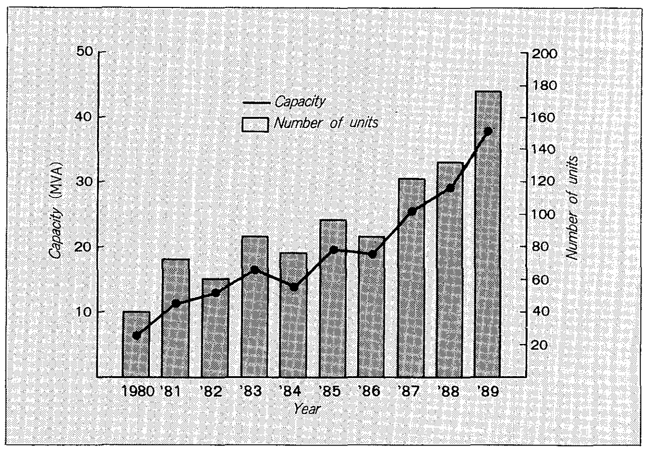


Table 1 Transition of bank on-line systems (for a certain city bank)

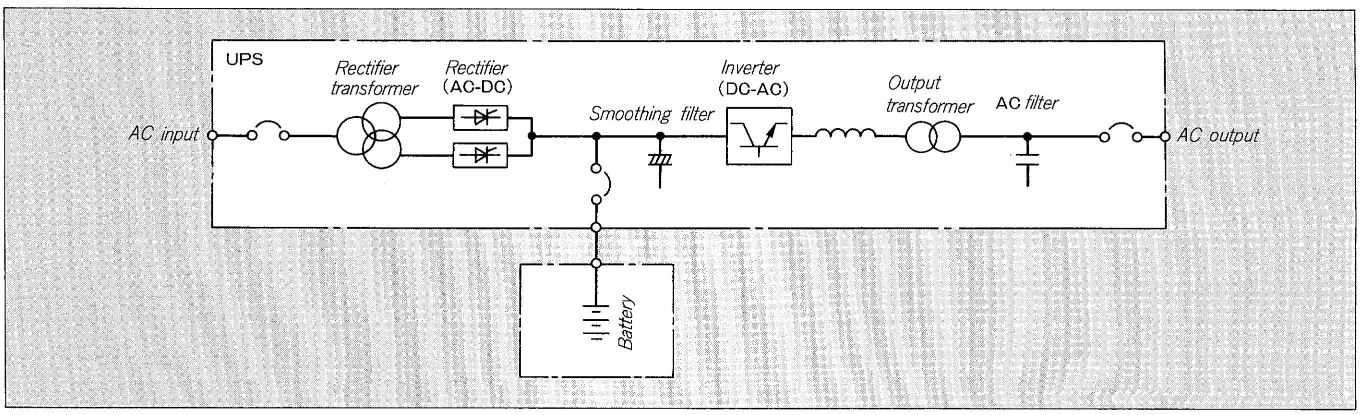
[From Nihon Keizai Shimbun (August 8, 1989)]

Item	1st generation on-line	2nd generation on-line	3rd generation on-line
Year started	1965	1975	1985
Host CPU processing capacity (MIPS)	0.4	8	235
Data capacity (bytes)	200 million	18 billion	1.4 trillion
Number of terminals	1,500	2,600	8,700
Program development amount (steps)	500,000	1.8 million	8 million
Investment (information machinery)	–	–	100 billion ~ 150 billion (nationwide 3 trillion)
Estimated UPS capacity (for office center)	500 kVA	2,500 kVA	7,500 ~ 10,000 kVA

Table 2 Standard specifications of 3-phase output UPS

Item		Specifications									
Input conditions	Voltage	372V ± 10%									
		200V		200V or 415V or 6,600V						415V or 6,600V	
	Frequency	50Hz or 60Hz ± 5%									
	Number of phases and number of wires	3 phases, 3 wires									
Output conditions	Rated capacity (kVA/kW)	100/80	150/120	200/160	250/200	300/240	400/320	500/400	600/480	750/600	1,000/800
	Voltage	200V, 210V, 220V (50Hz only), 230V (60Hz only), 415V								415V	
	Frequency	50Hz or 60Hz									
	Number of phases and number of wires	3 phases, 3 wires or 3 phases, 4 wires									
	Load power factor	0.7 (lagging) ~ 1.0, rated 0.8 ~ 0.9 (lagging)									
	Voltage accuracy	±1.5%									
	Transient voltage change	±8% Conditions (1) At 40% step load change (2) At input voltage ±10% sudden change (3) At utility power failure and recovery (4) At 1 unit selective tripping (5) UPS ⇄ bypass transfer However, (1) to (5) above shall not overlap.									
	Response time	100 ms									
	Waveform distortion	5% (square average value of all harmonics at 100% linear load) 3% (single harmonic maximum value at 100% linear load) 10% (square average value of all harmonics at 50% rectifier load)									
	Voltage unbalance between phases	±3% (when ratio of current between phases is 1.3)									
	Frequency accuracy	±0.1% (for internal oscillation)									
	External synchronization range	±1%									
	Overload capacity	120% for 1 min. 150% for 10 secs (operation guaranteed value)									
	Overcurrent limit value	150% (when overcurrent exceeds 150%, current drooping characteristics acts and overcurrent is limited to 150% or less)									
	Output phase error	120° ± 1° (balanced load) 120° ± 3° (30% unbalanced load)									
	Voltage adjustment range	±5% (rated load)									
Others	Ambient temperature	–10 to +40°C (operating), recommended value +18 to +27°C									
	Relative humidity	30~90%									
	Noise	65~75dB									
	Dielectric strength Insulation resistance	2,000V for 1 min (main circuit) 3MΩ or greater (500V megger)									

Fig. 2 Main circuit system



circuit of the 3-phase UPS is shown in *Fig. 2*. An exterior view is shown in *Fig. 3* and the outline dimensions are shown in *Table 3*.

Ample advantage is taken of the self-quenching ability, high speed, high reliability, low kW loss, and other features of the power transistor and a high performance, high efficiency, and high reliability inverter backed by high frequency PWM control technology is formed at the inverter section.

The use of a 12 pulse rectifier received favorable comment, but today, when there is a strong call for high quality electric power, including reduction of the harmonic current generated by modern electronic equipment, there are cases where even the 12 pulse rectifier mentioned above is unsufficient with large-scale systems like several 500kVA paralleled system. This point is discussed later.

3. LARGE-SCALE POWER SYSTEM

Here a system which supplies power to a computer by running several large capacity UPS in parallel is called a large-scale system and the problems created by such a system and their solution are explained.

Fig. 3 Exterior view of 3-phase output UPS

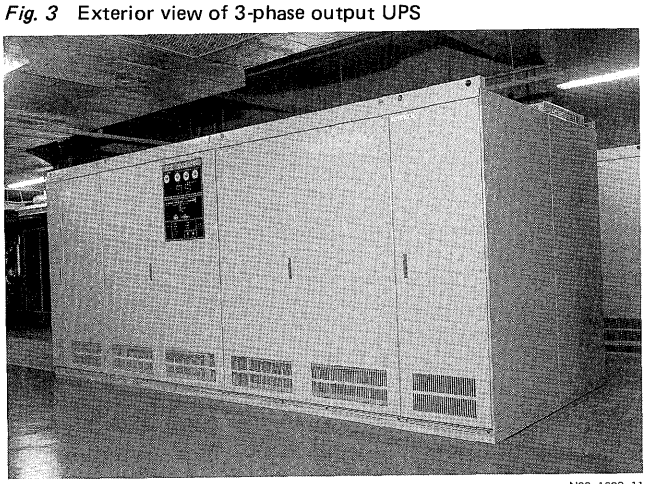


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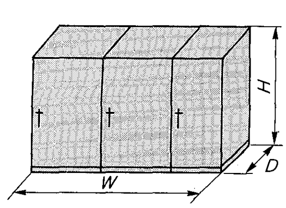
Table 3 Outlines dimensions of 3-phase output UPS

Capacity (kVA)	*W* (mm)		*D* (mm)	*H* (mm)
	6.6 kV input	372 V input		
100	–	1,600	800	1,850
150	–	2,000	800	1,850
200	3,400	2,200	800	1,850
250	4,000	2,400	1,000	1,950
300	4,000	2,400	1,000	1,950
400	5,200	3,200	1,000	1,950
500	5,600	3,600	1,000	1,950
600	6,400	4,200	1,000	1,950
750	6,800	4,600	1,300	2,350
1,000	8,000	5,600	1,300	2,350



3.1 UPS system configuration

This section outlines the system configuration of the UPS. Generally, from the standpoints of load capacity and reliability, a single module UPS is insufficient for a large-scale system and several UPS are paralleled. In short, it is well known that the objectives of UPS paralleling are increase of power capacity and improvement of reliability by redundant operation. Various UPS system configurations are practicalized, centered about the basic UPS (single system without bypass). Typical examples of this configuration are shown in *Fig. 4*. These system configurations are grouped by inverter operation method, transfer method between UPS and bypass, redundancy system, number of power supply systems, etc. Parallel redundant operation with static bypass (No. 8 of *Table 4*) is very often used with large-scale systems.

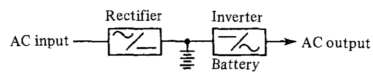
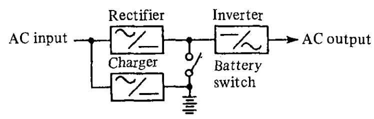
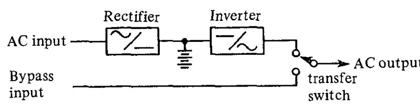
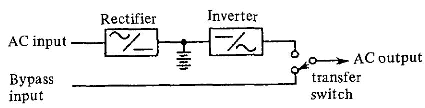
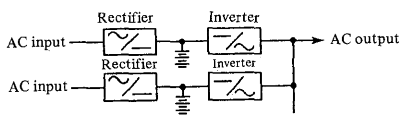
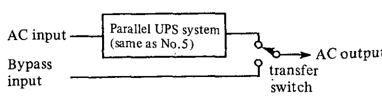
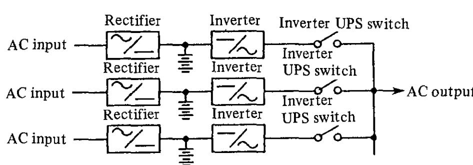
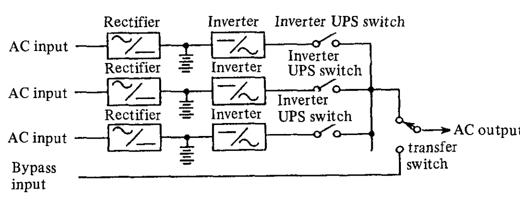
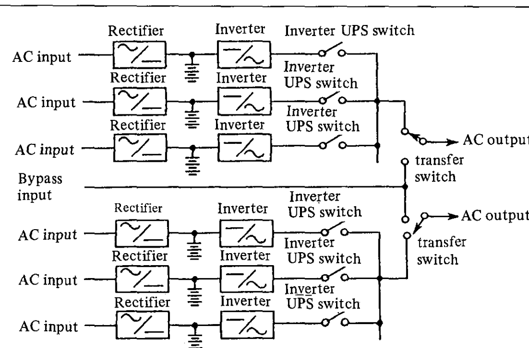
On the other hand, when the number of parallel units is increased, because the drop in reliability with the increased number of units is of concern, for a computer center requiring a tremendous amount of power, power is supplied by dividing the power system and load system into several independent systems. This can suppress the output current to several thousand amperes (2,500kVA at 200V) even when the output voltage is 200V and is also desirable from the standpoints of economy and reliability.

Recent on-line systems are advancing to nonstop systems, including during maintenance and many are being installed as host computer back-up units. In such cases, high reliability systemization to distribute the danger by multisystemizing the power supply also is important. For these, not only the reliability of the power system itself, but also extension to reliability (parts and functions reliability) as an entire system, including load system and human operation errors, work errors, etc. should be considered.

Redundancy is also desirable in terms of maintenance, and because it is difficult to shut down a nonstop system which runs 24 hours a day, 365 days a year even for routine maintenance, sequential maintenance and inspection can be performed by using redundant units. With such a large-scale system, even serviceability should be amply evaluated.

Usually the number of redundant units in parallel redundant operation is one. That is if the number of paralleled units is made N. power can be supplied to the entire load by (N-1) units. Because power can be supplied continuously even if one of the N units stops and the failed unit can be recovered during this time, reliability as a power system is high. Using two redundant units can prevent the loss of power if the operating UPS should fail while one UPS is shutdown for maintenance. However, because the reliability of each UPS is extremely high, the probability of one system failing during the short time that the other system is being serviced and inspected is virtually zero and the effect of two redundant units in proportion to

Table 4 UPS configuration (JEC-2431-1895 referenced)

No.	System configu-ration	Bypass	System name	System block diagram	Remarks
1	Single	No	Rectifier/charger		Basic UPS. The rectifier is an example of a "charger type" with battery charging function.
2			Battery switch		The battery is normally separated from the inverter. When a power failure occurs, the battery switch is turned on. The battery switch is a semiconductor siwtch.
3		Yes	Inverter main supply		Usually, the number of examples of application of this system is large. When a semiconductor switch is used as the changeover switch, it becomes a "utility power no-break switching system".
4		Yes	Inverter standby operation		This system is also called a "normal utility power supply system". It is used with the low capacity UPS of personal computers.
5	Parallel	No	Parallel UPS		The figure is an example of a two UPS system. There are no restrictions on the number of paralleled units. However, there is no redundancy.
6		Yes	Parallel UPS with bypass		Same as above.
7	Parallel redundancy	No	Parallel redundant operation		An example of three parallel UPS is shown.
8		Yes	Parallel redundant operation with static bypass		When a semiconductor is used as the changeover switch, this system is called a "parallel redundant uninterruptible backup system". It is the basic large-scale UPS system.
9			Double parallel redundant operation system with static bypass		This is two systems of No. 8. It is used with ultra-large-scale systems. This example is two systems, but is expanded to three or four systems, depending on the load capacity.

investment is small.

The battery configuration will be touched upon here. Because a battery is normally used as stand-by, a battery is often installed as common from economical view point even if the UPS is parallel redundant. However, with a UPS, the battery must function positively when necessary (at a power failure). Just because it is nor normally used, it does not mean that redundancy is unnecessary. Because a battery has a short expectancy life of several years (lead acid storage battery), it must be renewed midway and expanded with load increases.

When the UPS failure rate and the possibility of utility power disturbances, including momentary interruptions, are evaluated, since the latter is much higher, failure of the utility power during battery replacement work shall be considered. Therefore, for a common battery, reliability is reduced and work safety also becomes unstable.

With recent large-scale system like this, the number of cases in which a redundant configuration including the battery is used is increasing. From the standpoint of the circuit, a battery is installed at each UPS as shown in *Table 4*.

3.2 Output overcurrent countermeasures

Generally, output devices using semiconductors have a low overcurrent capability. UPS has same problem also, because the overcurrent capability of the semiconductor elements themselves is low. When using a UPS, this point should be amply recognized in system planning.

The overcurrent capability of a UPS is designed with the characteristic of *Fig. 4*. In particular, a current exceeding 150% must not flow for even as short a time as 0.01 second. When a current exceeding the rated value flows, the current limiting protection operation is performed quickly (1ms or less) and the voltage is dropped abruptly. Therefore, the system is considered to be stopped also.

Even with an amply managed computer system, the overcurrent capability can be exceeded by the starting inrush current or an overcurrent can be generated by short-circuit of a load device, but for a large-scale system, the inrush current does not have to be considered. However, there are so many numbers of load devices and the occasional generation of a short-circuit fault at those should be taken into account.

Fig. 4 UPS overcurrent resistance

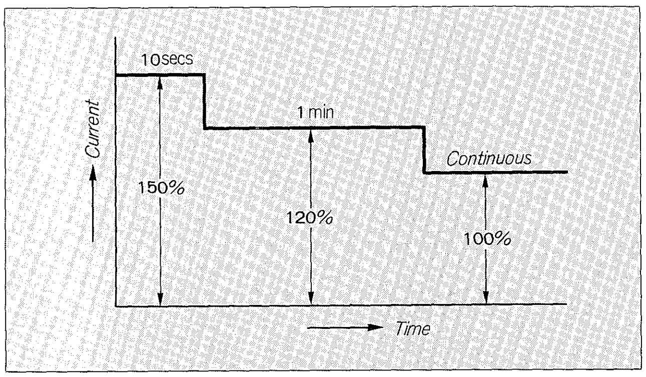
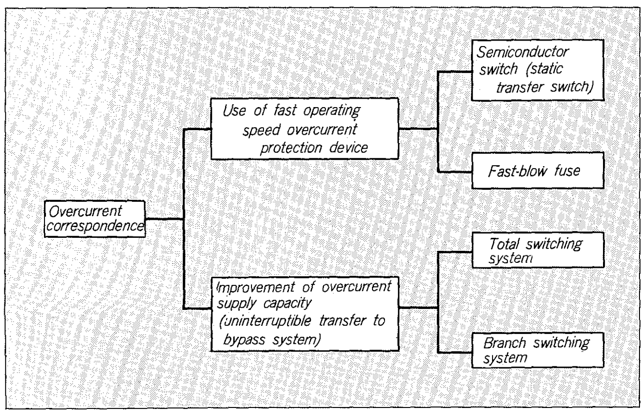


Fig. 5 UPS overcurrent coordination

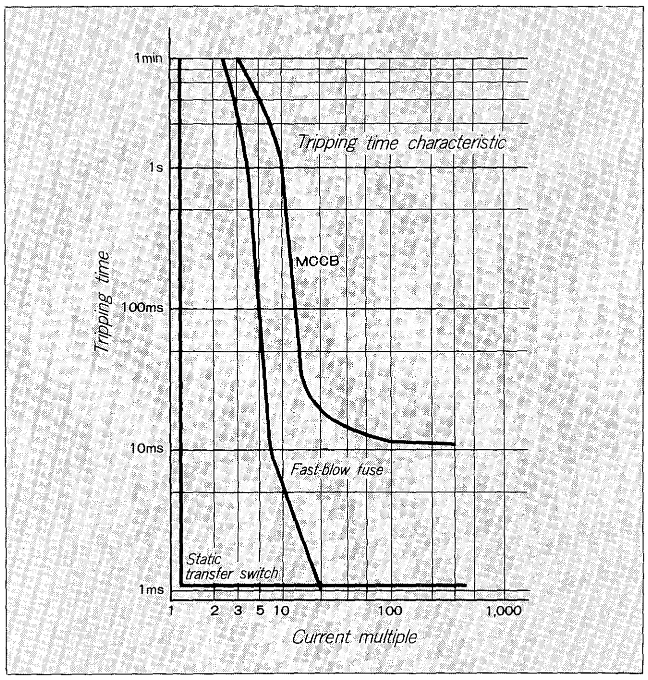


A typical overcurrent protection device is molded case circuit breaker (MCCB). However, since the tripping time is long, coordination of an MCCB and a UPS is difficult. Therefore, to coordinate the overcurrent protection device and UPS, an overcurrent protection device faster than the MCCB or a system with improved overcurrent supply capacity as an entire power supply system must be used as shown in *Fig. 5*.

When the overcurrent protection device is viewed from the standpoint of operating speed, as shown in the concept drawing of *Fig. 6* (main point: 10ms or less region), the static transfer switch is ideal, but it has disadvantages in terms of price -and size and since its installation at each load device is nearly impossible due to the above reasons, it is not used much. From this standpoint, the fast-blow fuse is also comparatively fast and is small and economical. Its use is limited by the fuse capacity and UPS capacity, but those are almost no restrictions with large-scale systems. However, the fuse has such draw-backs as the need for replacement after overcurrent, etc.

Recent UPS do not use a special overcurrent protection device, but often use a system uses a bypass system to improve overcurrent supply capacity and allows coordination with the MCCB. This method is backed by inter power supply no break transfer technology and performs no break transfer to the bypass system (utility power supply) simultaneously with generation of an overcurrent (since the overcurrent supply capacity of the bypass system is high, protection coordination with MCCB is easy) and performs no break transfer to the UPS power supply again automatically when the overcurrent system is tripped and the current recovers to normal. Because this transfer must

Fig. 6 Tripping characteristic concept of each current protection device



be performed instantly when an overcurrent is generated, the load is transferred to bypass by the static bypass switch.

Two typical examples of a no break transfer with bypass system are shown in *Fig. 7*.

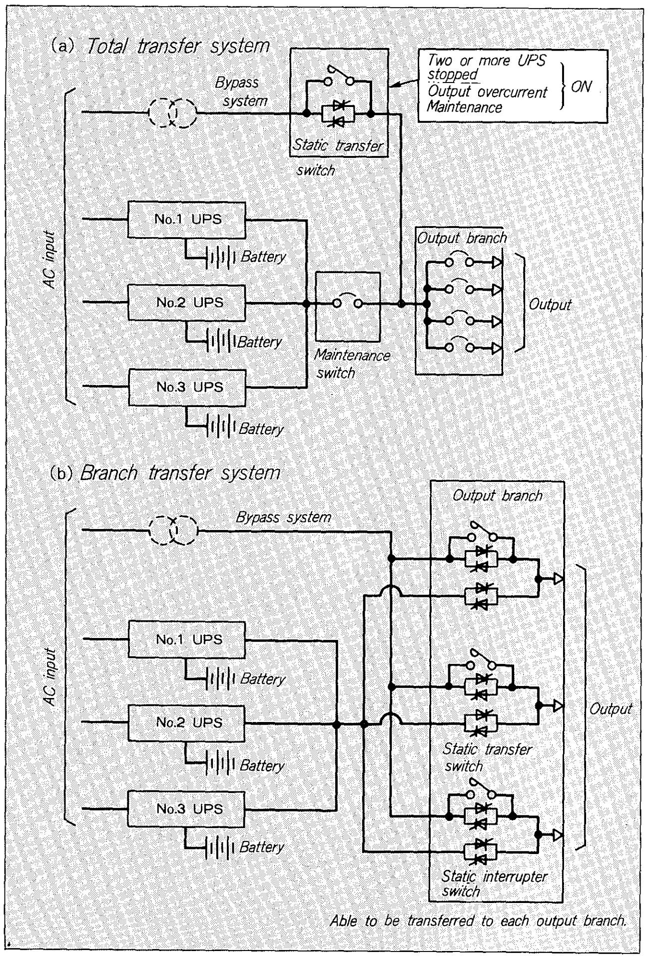
With the total transfer system, the transfer switch with the bypass system is installed for the entire paralleled UPS group and all the load systems are transferred to the bypass system due to an overcurrent at part of the load.

The branch transfer system is a method by which a transfer switch is provided for each output branch system of the UPS and only the faulty branch system is transferred and the UPS continues to supply power to the other branch systems. Both systems have advantages and disadvantages. Looking at the static transfer switch, the total transfer system has a large current capacity, but since the load of all the UPS are transferred to bypass at a same time and the inverter elements are tripped together at that time, a static interrupter switch is unnecessary at each UPS output side. For the branch transfer system, the current capacity of the static transfer switch is not too large, but since the number of the switches increases and transfer is performed for each branch, forced quenching is added to the UPS side static interrupter switch.

Because of this, the branch transfer system is larger and more expansive than the total transfer system, but since even if the load on a branch system is transferred to bypass, there is almost no affect on the entire system, therefore, the branch transfer system is often used with recent large-scale systems.

In either case, systems which use a bypass system are extremely important not only from the standpoint of output overcurrent countermeasures, but also power system reliability countermeasures. For example, since it is possible to cope with UPS simultaneous multiple unit trouble, common section maintenance, etc., to use bypass systems are expected to become the mainstream in the future.

Fig. 7 No break transfer with bypass



3.3 Input and output systems

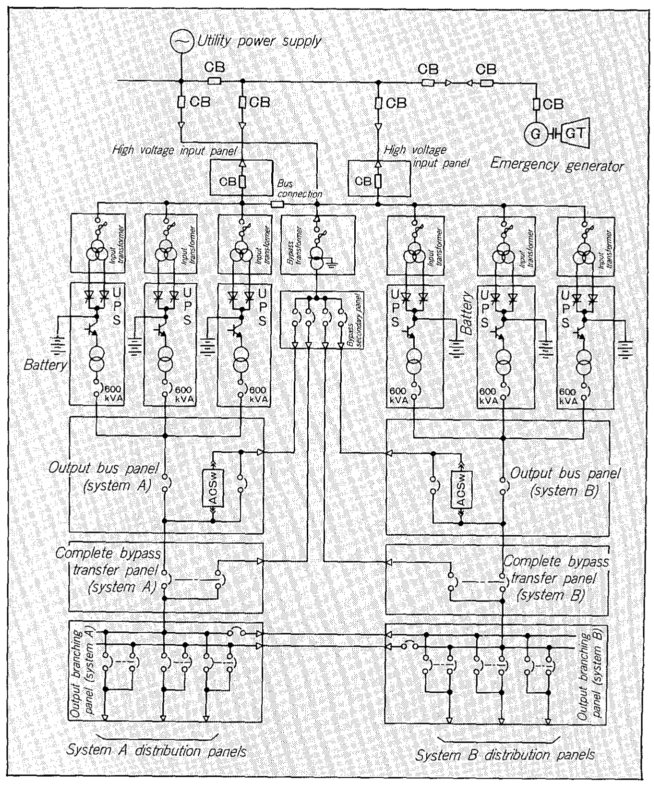
The input system which supplies power to the UPS and the output system which supplies power to the load system are also important parts of a UPS and systems balanced with the power system are necessary. Higher input and output systems reliability is based on duplication and redundancy and is achieved by UPS system expansion and renovation and by building a power distribution system which does not stop supplying power even during routine maintenance of the entire power supply facility, etc. Since conditions unique to each computer center often have priority, examples of two or three of the newest systems are introduced here.

(1) Example 1

Figure 8 is a 2,400kVA UPS made up of two parallel redundant systems consisting of three 600kVA UPS each.

The input supplies 6kV high voltage power to system A and system B and even if one power system cannot supply power to UPS, bus connection circuit breaker (CB) is connected and then, the healthy power system can

Fig. 8 Example 1



supply power to both UPS system. A bypass input is connected to each bus so that, at worst, bypass power can be supplied even during substation maintenance inspection. Because the bypass power is not normally used, it can be made common to both UPS systems.

To make the UPS more reliable, no break transfer with the bypass power supply is performed and the total transfer switching system, with its simple circuit configuration, is used. For maintenance inspection including the transfer circuit, a complete bypass transfer circuit is provided. Manual no break transfer can be performed without stopping the load by performing this transfer between UPS and bypass power supplies also.

The final output of systems A and B is branched by an output branching panel and power is supplied to each load system. Each branch circuit is such that either the system A or system B power supply can be selected for both systems load balance adjustment and maintenance convenience.

(2) Example 2

Figure 9 is a 6,000kVA UPS made up of three parallel redundant UPS systems consisting of five 500 kVA UPS system each.

Regarding the input, supply reliability is increased by making the 6 kV high voltage power supply two lines (main-standby switching) for each system. Connection between systems is performed by bus. The bypass power supply is made common, the same as Example 1. The

Fig. 9 Example 2

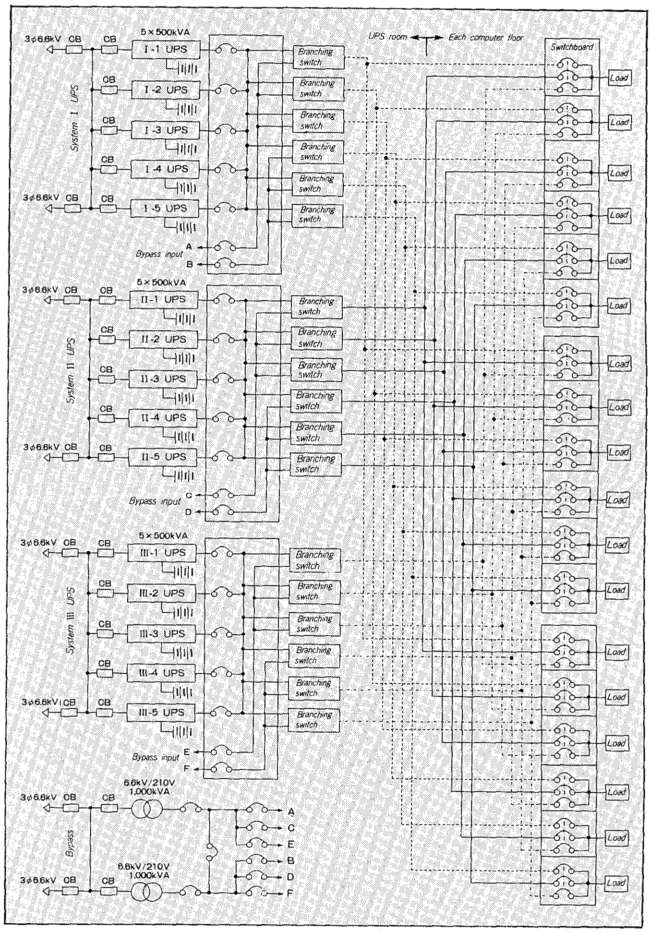
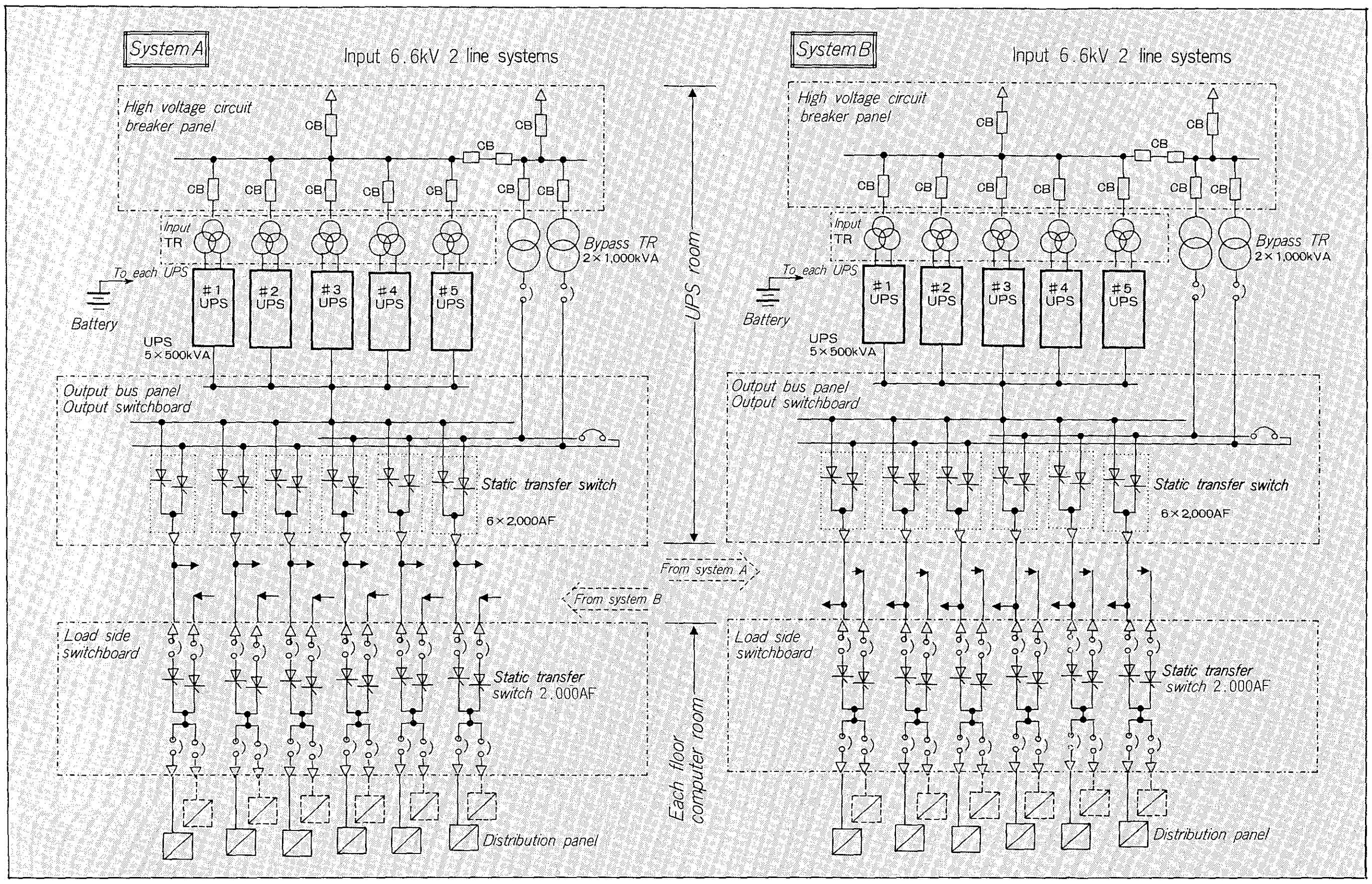


Fig. 10 Example 3



input is made separate for each UPS system.

The output of each system uses the branch transfer system and even if part of the load system is shorted, only the pertinent feeder is no break transferred to the bypass power supply. The branched output of each system is tripled so that system I, system II, or system III can be selected at the load side (computer floor) switchboard. This is done to increase the reliability of the output system and make it easy to contend with future forecasting of the load system.

(3) Example 3

Figure 10 is a 4,000kVA UPS made up of two parallel redundant systems consisting of five 500 kVA UPS system each.

At the input, supply reliability is increased by making the 6 kV high voltage power supply two lines for each system and providing a bus connection CB. A separate bypass power supply is provided for each system. Because of the large capacity transformer, it is divided into two units so that the bypass power supply can be used even if trouble should occur in one transformer. (However, capacity restriction is necessary.)

The output of each system uses a branch transfer system and is branched to six circuits and no break transfer with the bypass power supply is performed at each branch. Both systems UPS can be operated in synchronization with the bypass power supply. As a result, the UPS of both systems can be operated synchronously. A load side switchboard is provided on each load system floor and no break transfer of the power supply of both systems is performed by static transfer switch (thyristor type). The power supply side static transfer switch and load side static transfer switch are combined and four power supplies, that is, system A UPS, system B UPS, system A bypass, and system B bypass, supply optimum no break and uninterruptible power to each load system at load short circuit, overload, power supply equipment trouble, maintenance inspection, etc. When operating such a system, the ability to constantly monitor and accurately specify and judge the power supply and load conditions is vital and depending on the complexity of the system, automation of many of the parts by programmable controller, etc. is also necessary.

4. INPUT SYSTEM HARMONIC CURRENT COUNTERMEASURES

One of the reasons that harmonic current is increasing is the spread of electronic devices in the society. The UPS also generates harmonic currents from the input rectifier, the same as other electronic devices. The basis of harmonic current suppression measures in countermeasures at the generation source. Fuji Electric led the industry in the suppression of harmonic currents by making the UPS rectification system a 12 pulse rectifier. However, since the capacity of ultra-large-scale UPS is very high, the absolute amount of harmonic current increases and even the 12 pulse rectifier cannot be said to be perfect.

To suppress the harmonic current from the rectifier,

Table 5 Harmonic current content by rectification system

Harmonic number (n)	Harmonic content (%)		
	6 pulse rectification	12 pulse rectification	24 pulse rectification
5	20.00	–	–
7	14.29	–	–
11	9.09	9.09	–
13	7.69	7.69	–
17	5.88	–	–
19	5.26	–	–
23	4.35	4.35	4.35
25	4.00	4.00	4.00
29	3.45	–	–
31	3.22	–	–
35	2.86	2.86	–
37	2.70	2.70	–
41	2.44	–	–
43	2.33	–	–
47	2.13	2.13	2.13
49	2.04	2.04	2.04
Total current distortion (%)	30.02	14.17	6.60

Fig. 11 24 pulse rectifier by UPS combination

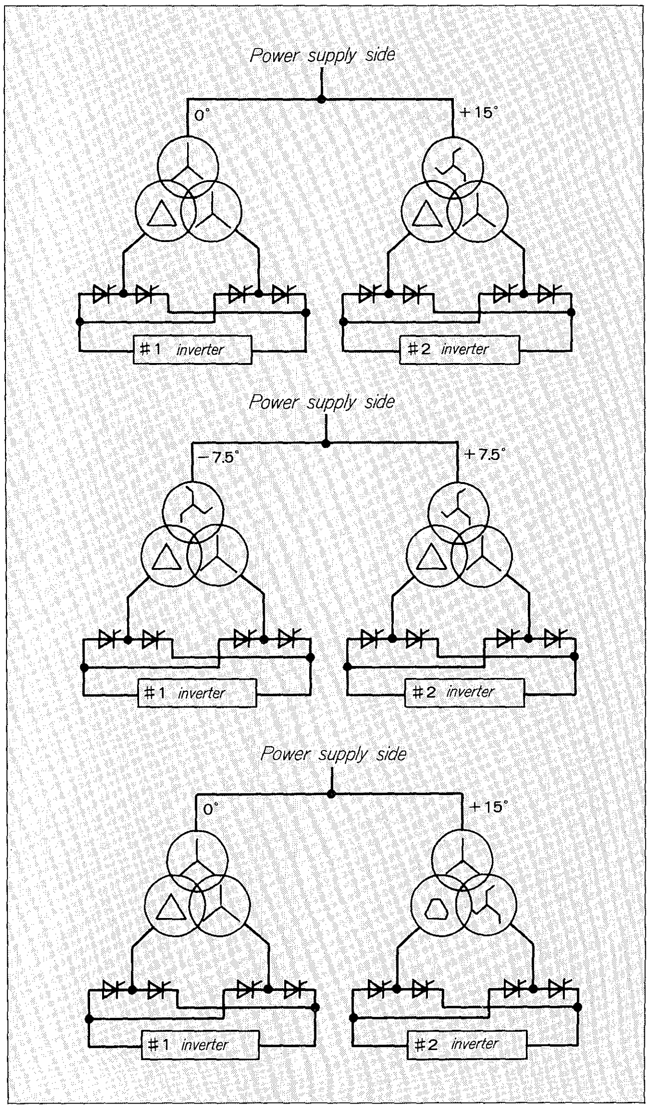
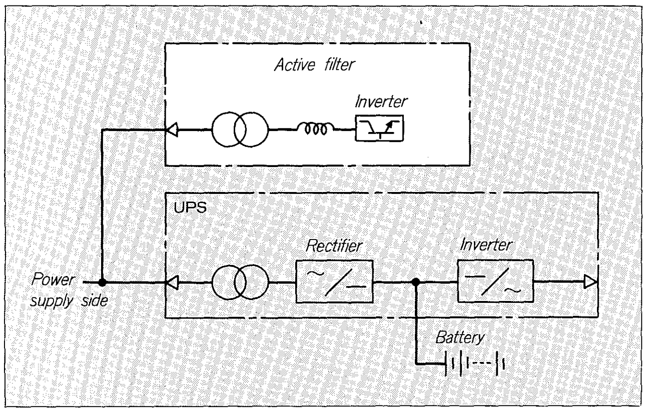


Fig. 12 Active filter system



the number of rectification phases is increased and a PWM rectifier is used and so forth. There are also passive filters (usually LC filters) and active filters, etc. as devices which absorb harmonic current. Since the UPS of a large-scale UPS system are paralleled, 24 pulse rectification can be realized by shifting the phase of the input rectifier transformer 15° for each UPS and operating 12 pulse rectifiers in parallel (multiplexing) as shown in *Fig. 11*. Various wirings can be considered by combining rectifier transformers. Typical examples are shown in this figure. As can be seen from *Table 5*, the 24 pulse rectification system can suppress harmonic current to 1/2 or less compared to the 12 pulse rectification system.

The recent advance of semiconductor and harmonic PWM control technology has attracted attention to the active filter. The active filter is a devices which canceled the harmonic current and prevents its flow to the system by passing a current of the same magnitude but of the opposite phase as the harmonic current generated from the rectifier by PWM inverter operation. When applied to a UPS, it is connected to the input system as shown in *Fig. 12*.

Because of the demand for high quality electric power, the active filter is forecast to become increasingly popular with the growth of the IGBT and other self-quenching type high-speed elements. We are especially confident that its application to large-scale UPS will increase.

5. CONCLUSION

The recent technical trend of large-scale UPS was described. In Japan, it is known that the information-network society is growing rapidly even when viewed from the rapid construction of large computer centers, centered about cities.

Regarding the contents introduced in this article, since economy and reliability are compatible, we feel that when this is viewed from the operating side, the system must be made automatic, semiautomatic, user-friendly, etc. and overall reliability increased further. The reliability of a simple UPS is high in terms of human engineering and this is also important.

Fuji Electric has taken "higher UPS reliability" as a basic creed for many years and has delivered many large scale UPS. This is nothing but a gift of evaluation and trust of customers for the Fuji UPS.