"UPS7000HX-T4" High-Efficiency UPS with Continuous Commercial Power Feeding and Quantity Control Functions

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ABSTRACT

In recent years, there has been increasing demand for uninterruptible power systems (UPSs) with increased efficiency used in data centers. To meet the demand, Fuji Electric has added the continuous commercial power feeding function to its "UPS7000HX-T4" three-phase four-wire UPS with normal inverter feeding. Continuously turning on the thyristors of the bypass circuit, the UPS receives power from commercial power source and feeds it to loads and charge the battery through the inverter. The maximum efficiency of the equipment reached 99% when turning off the rectifier. Furthermore, the quantity control function has been provided to operate with high efficiency during normal inverter feeding. Turning off the rectifier and inverter of the standby UPS increases the efficiency during light load operation.

1. Introduction

In recent years, there has been increasing demand to improve the efficiency of the uninterruptible power systems (UPS) used in data centers. Up until now, Fuji Electric has achieved high efficiency UPS for data centers by changing the switching voltage from 2 level to 3 level to reduce switching loss and LC filter loss[1]. In addition, our product line-up includes models that use silicon carbide (SiC), instead of silicon (Si), for inverse-parallel diodes in the rectifier[2]. Furthermore, we have produced a high-efficiency power supply system utilizing our "UPS7000HX-T4[3]," a 3-phase 4-wire system that can supply power directly from the UPS to the server.

To further improve efficiency, one solution is to change the operating mode from a normal inverter feeding system to a continuous commercial power feeding system. However, continuous commercial power feeding type UPSs have not been used much. Up until now, stabilized power supply has been achieved using normal inverter feeding systems, and continuous commercial power feeding systems will lower the power quality.

It is expected that a UPS having both a normal inverter feeding system and a continuous commercial power feeding system will achieve stabilized power feeding and high-efficiency operation. Therefore, Fuji Electric has added continuous commercial power feeding functions to the UPS7000HX-T4, which is a high-efficiency, 3-phase, 4-wire UPS equipped with normal inverter power feeding system. Furthermore, a quantity control function has also been added to enable high-efficiency operation during normal inverter feeding.

These functions make it possible to operate more efficiently than ever in systems that employ both continuous commercial power feeding and normal inverter feeding operating methods. The operating method can be selected according to the demand of the commercial power supply and quality of the power distribution to the load. Offering this model shortens the period from planning design to shipment, because it can be used for 3-phase 4-wire, 3-phase 3-wire systems, servers, and air conditioner loads. In addition to making maintenance easier, it also simplifies on-site installation and wiring work through conductor connection between the UPS panel and I/O panel. In this paper, we will introduce our "UPS7000HX-T4" high-efficiency UPS with continuous commercial power feeding and quantity control functions.

2. System Features

Figure 1 shows the external appearance of the UPS7000HX-T4 with continuous commercial power feeding and an I/O panel. Table 1 describes the specifications of the system. Figure 2 shows the main circuit of the "UPS7000HX Series," using a double-conversion system with normal inverter feeding, to which a continuous commercial power feeding function is added. In the bypass circuit, a thyristor switch and magnetic contactor (MC) are connected in parallel. During bypass transferring, the thyristor switch and MC are turned on in order. After this, the thyristor switch is turned off. Therefore, specifications adopted a short single-cycle rating with a rated output of 800%. However, our recent development adopts a continuous rating so that power can be supplied from the thyristor continuously. The I/O panel has been designed with a thyristor switch, AC input, AC output and molded-case

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Fig.1 Outer view of UPS panel and I/O panel (UPS on left; I/O panel on right)

Table 1 "UPS7000HX-T4" specifications

Item		Specifications
AC input	Wiring	3-phase 4-wire
	Voltage	400 V ±10%
	Frequency	50/60 Hz
	Power factor	0.99 (delayed) or higher
Bypass input	Wiring	3-phase 4-wire
	Voltage	400 V ±10%
	Frequency	50/60 Hz
	Bypass overload capability	800% Single-cycle (thyristor short time)
AC output	Rated capacity	500 kVA
	Wiring	3-phase 4-wire
	Voltage	400 V
	Voltage tolerance	<±1%
	Frequency	50/60 Hz
	Frequency precision	±0.01 Hz (during self-oscillation)
	Load power factor	Rating 1.0 (0.7 lag to 1.0)
	Transient voltage regulation	<±5%
	Voltage waveform distortion factor	2% or less (linear load), 5% or less (nonlinear load)
	Overload capacity	125% × 10 min.; 150% × 1 min.
Battery	Rated voltage	480 to 528 V
	Floating charge voltage	540 to 594 V
Others	Dimensions	W1,600 × D1,000 × H1,950 (mm)
	Communication interface	MODBUS*

*MODBUS is a trademark or registered trademark of Schneider Automation, Inc.

circuit-breaker (MCCB) for the battery.

During continuous commercial power feeding, the thyristor switch is continuously turned on, enabling commercial power to be supplied to the load. During this operating, the rectifier is stopped and the inverter runs in the active operation so that it can charge the battery and improve the input power factor*1.

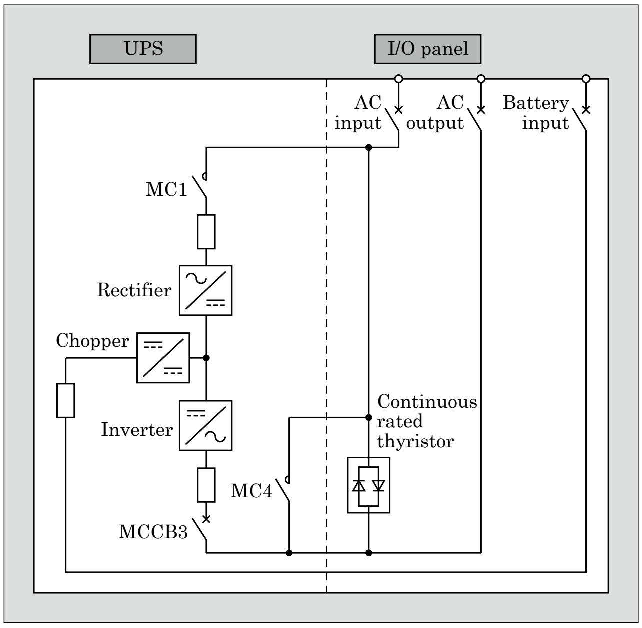

Fig.2 "UPS7000HX-T4" main circuit configuration

Conventionally, the UPS panel and I/O panel have been connected via an external cable. However, we have connected them using an inter-panel conductor connection. On-site construction can be simplified by integrating the UPS panel and I/O panel. Furthermore, since there is no external cable connection, it is also visually appealing.

3. Continuous Commercial Power Feeding System

During continuous commercial power feeding, power is supplied directly to the load from the commercial power supply, and the inverter is activated only to charge battery and improve input power factor. Therefore, the load factor of the inverter is extremely lower for continuous commercial power feeding than for normal inverter feeding. Furthermore, since the rectifier is completely stopped, the efficiency during continuous commercial power feeding exceeds 99% at the rated capacity.

3.1 Transferring control

When power failure, serious failure or overcurrent occurs during continuous commercial power feeding, the system transfers to the inverter so that it can supply power at a stabilized power quality.

Figure 3 shows the transferring control from continuous commercial power feeding.

(1) Power failure transferring

In the event of power failure, the system transfers

*1: Active operation refers to running an effective current to the thyristor by supplying reverse-phase current for the reactive current and harmonic current of the load currents.

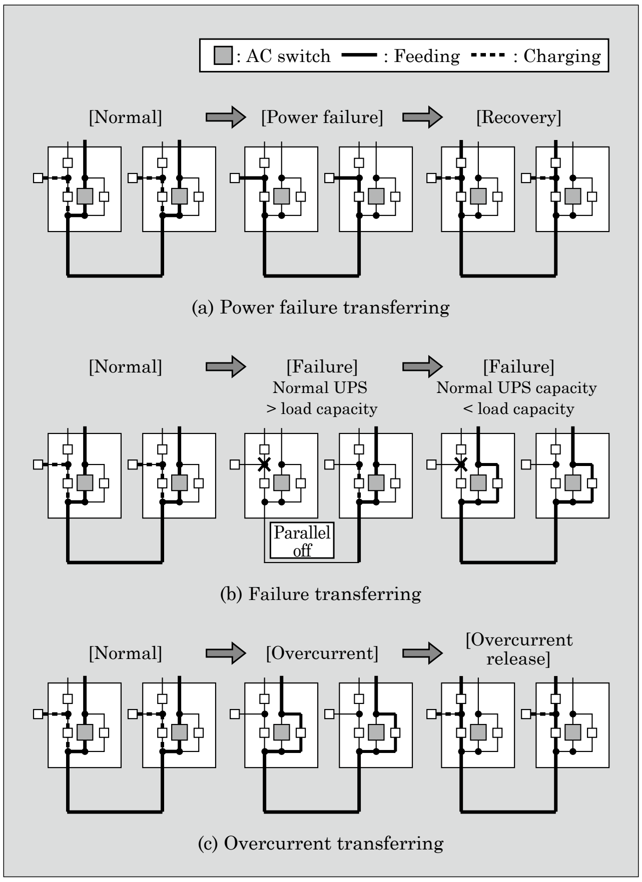

Fig.3 Transferring control during continuous commercial power feeding

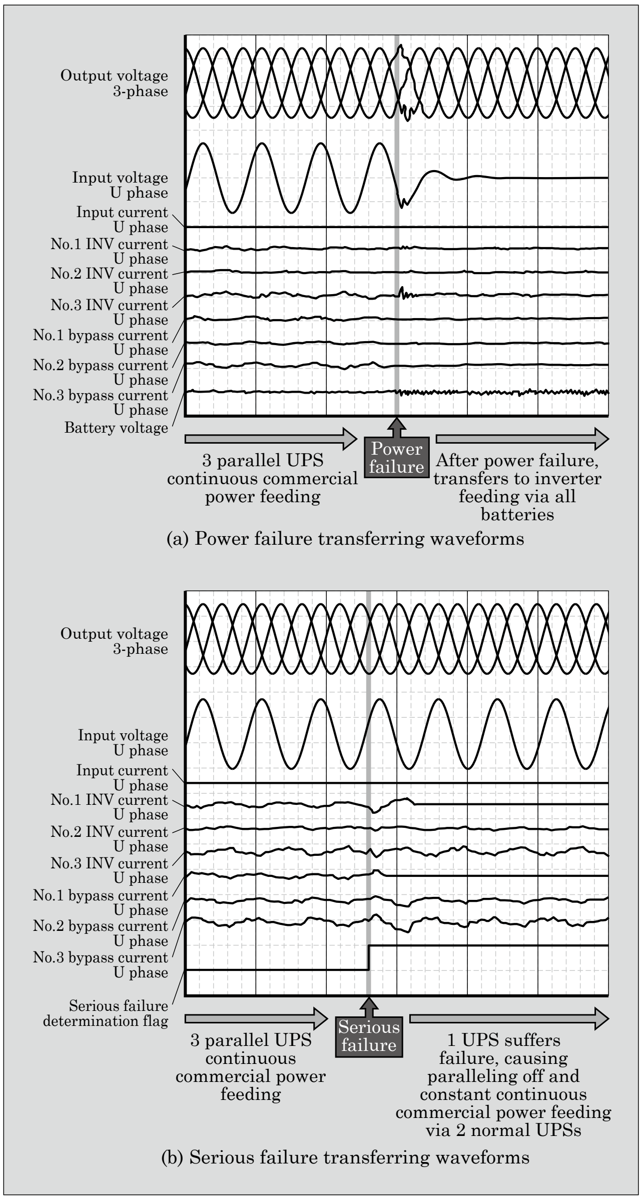

Fig.4 Transferring waveforms during continuous commercial power feeding (with 3 parallel units)

to battery operation. When power is restored, it automatically transfers from the battery operation to normal inverter feeding. It does not automatically return to continuous commercial power feeding. Therefore, after a power failure, continuous commercial power feeding must be activated manually. The operating principle of the system is to return to normal inverter feeding so that frequent transferring will not occur in the event that there are consecutive power failures following the initial failure. During normal inverter feeding, a stabilized source of power can be supplied without transferring during power failures.

(2) Failure transferring

In the event that a UPS suffers a serious failure, paralleling off will occur and a normal UPS will maintain continuous commercial power feeding. If the UPS detects overload, the system will transfer to bypass power feeding.

(3) Overcurrent transferring

In the event of overcurrent, the system will transfer to bypass power feeding. When the overcurrent is resolved, it will return back to normal inverter feeding. As mentioned above, continuous commercial power feeding must be activated manually.

Figure 4(a) shows the transferring waveforms when a power failure occurs during continuous commercial power feeding. Since the inverter is in a state of active operation, the system transferring without instantaneous power interruption. During normal operation, each UPS inverter runs active operation independently. After a power failure, the system will transfer to parallel operation of the inverters using the battery.

Figure 4(b) shows the transferring waveforms when a serious failure occurs during continuous commercial power feeding. When a serious failure occurs in the inverter, the inverter is turned off, and after the bypass MC4 is turned on, the thyristor is turned off. After shunting the commercial power supply to the thyristor and MC, the thyristor is turned off, ensuring that there is no waveform disturbance.

3.2 Design of peripheral equipment for continuous commercial power feeding

During continuous commercial power feeding for paralleling systems, the load is shared according to the impedance of each UPS. Two type of power feeding methods are available for the parallel UPS system: power feeding through individual transformers or a common transformer.

In the case of the common transformer, the impedance is determined by the length of the cable up to the point of paralleling. It is difficult to prepare all cables at the same length. As a result, there is generally a 6 to 20 m difference in length, and this impacts load sharing, since it is dependent on cable length. Therefore, a balance reactor is required for the bypass circuit of the UPS to balance load sharing. In the case of individual transformers are used, the load is shared according to the combined impedance of the transformer and cable impedance.

The variation in the percentage of impedance of Fuji Electric mold transformers is less than +1.5% to −1.0%, relative to the average value. Furthermore, the impedance ratio of the cable to transformer is about an order of magnitude smaller.

In the worst case scenario, the load sharing was ±5% when connection was made with the transformer and cable impedance in ascending order. To deal with this, the ratings of equipment, such as transformers, cables and circuit breakers, have a tolerance of approximately 5%.

4. Quantity Control for Normal Inverter Feeding Systems

4.1 Standby UPS loss reduction and quantity control efficiency characteristics

When the no-load loss of a UPS can be smaller in standby mode during quantity control than in normal operation, operational efficiency can be improved. On the other hand, the battery needs to be continuously charged for the UPS while it is in standby mode. In a normal inverter feeding system, the rectifier is controlled to have a power factor of unity. However, the current of a fully charged battery is extremely small, so it is not necessary that the power factor of the UPS during standby mode be unity. Moreover, the loss of the 3-phase full-wave rectifier with diodes is extremely smaller than that of PWM control, and therefore, the standby UPS performs 3-phase full-wave rectification using the feedback diodes connected in inverse-parallel to the IGBTs without switching the IGBTs, main devices of the rectifier.

The battery is charged using the chopper circuit. The pulse control circuit is activated with the IGBTs of the inverter being turned off in preparation for parallel operation. This allows all cooling fans in the main circuit stack of the rectifier, chopper and inverter to be stopped. As a result, the loss of the standby UPS can be reduced to approximately 200 W. As shown in Fig. 5, during parallel operation of eight units, using quantity control can improve efficiency at light loads.

4.2 Quantity control method

The number of units in operation needs to be configurable so that the UPS will not transition to bypass power feeding with the overload capability is being exceeded even when the load rises sharply. The UPS overload capability is 125% for 10 minutes and 150% for 1 minute. The load factor of each UPS needs to be 150% or less during load spikes. In a parallel redundant system (8 units × 500 kVA) with a system capacity of 3,500 kW, 3,500/(1.5 × 500) = 4.7 indicates that the minimum number of units in operation should be 5.

On the basis of the minimum number of required units in operation, a load factor is determined according to the increase in efficiency before and after changing the number of units. In particular, the load factor is set to approximate 70% when the load increases and approximately 45% when the load decreases.

The system comes with a function for smoothening the operation integration time of each UPS; the UPS with the shortest total operation time becomes the next to operate and the UPS with the longest total operation time becomes the next to turn off.

4.3 Transferring control during quantity control

In the event of power failure of the input power supply, overload or serious failure, the system will basically transfer from quantity control to all-unit operation automatically. After confirming the soundness of the system, operators can manually transfer to quantity control at their own discretion.

For example, if a power failure occurs while operating 5 units, the 5 units will instantly transfer to battery power. The 3 standby units are put into parallel operation after about 3 seconds. Furthermore, if there is a serious failure in 1 of the 5 units and only 4 units are operable, after about 13 seconds, all the UPS sys-

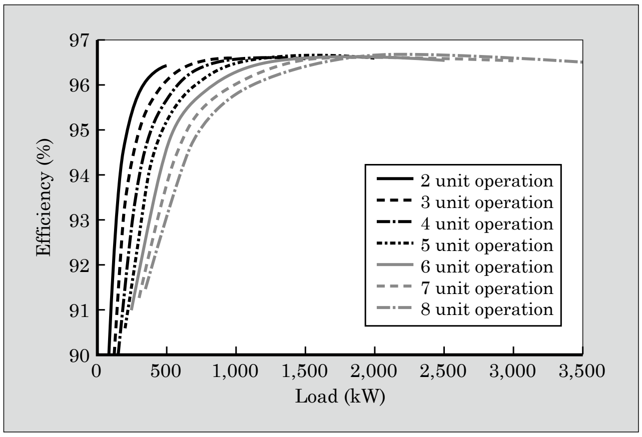

Fig.5 Efficiency characteristics for the number of units in operation (2 to 8 units)

tems in standby mode will be put into parallel operation.

5. Reliability of Normal Inverter and Continuous Commercial Power Feeding Systems

(1) Comparison of Failure In Time (FIT) during single-unit operation

Table 2 shows a comparison between FIT*2 (normal inverter feeding system is 100%) and transferring control for normal inverter feeding systems and continuous commercial power feeding systems.

During continuous commercial power feeding, since the number of rectifier components is large and the rectifier itself is not activated, FIT will be smaller than during normal inverter feeding, enabling highly reliable operation.

(2) Comparison of reliability during failure

In the event of a failure, the normal inverter feeding system will perform 4-step transferring control, consisting of inverter turn-off, thyristor switch turn-on, MC turn-on and thyristor switch turn-off. In contrast to this, the continuous commercial power feeding system performs 3-step transferring, consisting of inverter turn-off, thyristor switch turn-off and MC turn-on, thereby reducing the number of transfers and lowering the risk of transferring failure compared with the normal inverter feeding system.

Table 2 Comparison of normal inverter feeding system with continuous commercial power feeding system

Item	Normal inverter feeding system	Continuous commercial power feeding system
Comparison of FIT* for single-unit operation	○ 100% Rectifier on, inverter on, Thyristor switch off	◎ 90% Rectifier off, inverter on, thyristor switch on
Transferring control during failure	○ 4-step Inverter off ⇒ thyristor switch on ⇒ MC turn-on ⇒ thyristor switch off	◎ 3-step Inverter off ⇒ thyristor switch off ⇒ MC turn-on
Transferring control during power failure	◎ 1-control Rectifier on → off (Continuous inverter operation)	○ 2-control Thyristor switch on → off Inverter active operation → Inverter feeding

*Cooling fans are excluded because they are redundant.

*2: FIT (Failure in time) is an indicator of the product failure rate, corresponding to the average number of failures per billion (10^9) hours of operation. $1/10^9$ (failures per hour) corresponds to 1 FIT.

(3) Comparison of transferring control reliability during power failure

During a power failure, the normal inverter feeding system simply stops the rectifier without changing the inverter feeding. In contrast to this, the continuous commercial power feeding system requires that the thyristor switch be stopped and that the inverter undergoing active operation be transferred to normal inverter feeding. Therefore, there is a risk of failure in inverter operation transferring and thyristor switching. As power failure occurs several times a year, it is necessary to recognize that there is considerable risk of transferring failure when using the continuous commercial power feeding system.

When comparing the frequency of failure and power failures, the number of power failures is overwhelmingly larger. Therefore, when utilizing continuous commercial power feeding systems, which are susceptible to transferring failure during power failures, it is recommended that a highly reliable system, such as dual redundant system, be used.

6. Postscript

In this paper, we introduced our “UPS7000HX-T4” high-efficiency UPS with continuous commercial power feeding and quantity control functions. We have improved the operational efficiency of our 3-phase 4-wire UPS7000HX-T4 by providing it with a continuous commercial power feeding function and a quantity control function during normal inverter feeding. This enhancement makes it possible to achieve high-efficiency power management systems for data centers. In the future, we plan to continue contributing to society through our high-efficiency and space-saving products.

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