"UPS7000HX Series" and "UPS6000DX Series," Using Lithium Ion Batteries

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ABSTRACT

There has been increasing demand for large-capacity uninterruptible power systems (UPSs) for data centers and other facilities that require a stable supply of power. Fuji Electric has developed a large-capacity UPS system that uses lithium-ion batteries (LIBs). The system employs highly reliable LIBs manufacturing by Samsung SDI and comes equipped with a battery management system that ensures the safe operation. The LIBs, having a life expectancy of 15 years, will be used without replacement during the entire life of the UPS main body. The installation space of the LIB is only 53% that of a lead-acid battery, achieving space saving.

1. Introduction

The development of the information age has brought about increased demand for large-capacity uninterruptible power systems (UPS) that provide a stable supply of power. The data center field in Japan is expected to further grow because of the need for new types of data processing, such as cognitive computing*1, AI and the Internet of Things (IoT), in addition to expanded use of cloud services. In such circumstances, UPS systems are required to operate stably and efficiently and need to be installed in smaller spaces.

Lead storage batteries have been conventionally used as the backup power supply of UPS systems. These lead storage batteries are low-cost and have high reliability. However, they have the disadvantages of being heavy and large and having a low energy density. Lithium ion batteries (LIB), which are superior to lead storage batteries, provide high energy density, high voltage, and small size, and they are used in many industrial products. The application of LIBs has been expanded mostly to mobile devices, and they are also being rapidly used for electric vehicles and power storage facilities. However, LIBs are not being used for large-capacity UPS systems that much. This is because UPS systems are installed in the electric room of buildings. An LIB uses electrolytes having fire risks like petroleum. Facilities that store or handle a large amount of LIBs need to take certain measures as dangerous facilities in accordance with the Fire Services Act.

Fuji Electric has employed Samsung SDI's LIB that can be expected to save space on large capacity UPSs such as the "UPS7000HX Series" and "UPS6000DX Series."

2. Outline of UPS

2.1 Specifications of the UPSs and LIB

Figure 1 shows the appearance of the "UPS7000 HX-T3," which uses lithium ion batteries, and the LIB unit (one rack), and Table 1 shows the specifications of the "UPS7000HX-T3" and "UPS6000DX-T3."(1) Table 2 shows the specifications of the LIB unit, and Fig. 2 shows the connection diagram of the UPS system and the LIB unit. One rack of the LIB unit has one series

(a) "UPS7000HX-T3"　(b) LIB unit

Fig.1 Appearance of "UPS7000HX-T3" and LIB unit

*1: Cognitive computing: A system that causes computers to not only process instructions given from humans but also thinks and learns like humans to present materials that help human decision-making.

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Table 1 Specifications of “UPS7000HX-T3” and “UPS6000DX-T3”

Item		UPS7000HX-T3	UPS6000DX-T3
AC input	Circuit system	UPS double conversion	
	Rated voltage	415/420 V (440 V)	200/210 V
	Input power factor	0.99 (delay) or more	
	Rated frequency	50/60 Hz	
	Harmonic current (total)	5% or below	
Bypass input	Rated voltage	415/420 V (440 V)	200/208/210 V (220/230/380/400/ 415/420/440 V)
	Voltage range	±10%	
	Rated frequency	50/60 Hz	
Inverter output	Rated output apparent power	500 kVA	100/150/200/ 250/300 kVA
	Rated output active power	500 kW	100/150/200/ 250/300 kW
	Rated power factor	1.0	
	Rated voltage	415/420 V (440 V)	200/208/210 V (220/230/380/400/ 415/420/440 V)
	Voltage distortion factor (100% linear load)	2% or below	
	Voltage distortion factor (100% rectifier load)	5% or below	
	Voltage accuracy	Within ±1%	
	Transient voltage fluctuation	3% or below (at 100% sudden load change)	4% or below (at 100% sudden load change)
		2% or below (at 10% sudden input voltage change)	
		2% or below (at AC input blackout and restoration)	1% or below (at AC input blackout and restoration)
		5% or below (when switched from bypass to UPS)	
	Settling time	50 ms	
	Overload capacity	125% × 10 min, 150% × 1 min	
	Frequency accuracy	±0.01% (at internal oscillation)	
	External synchronous frequency range	50/60 Hz ± 5%	

circuit having a predetermined voltage and capacity. Components are installed in the order of a conductor for parallel connections, switchgear, a switching-mode power supply (SMPS) assembly, and battery modules from the upper shelf. The battery management system (BMS) monitoring these components consists of a system BMS, a rack BMS and module BMSs.

The switchgear includes a protection circuit and a rack BMS. The rack BMS collects all the information related to the rack and monitors the state of all the

Table 2 Specifications of LIB unit per rack

Item	UPS7000HX Series	UPS6000DX Series
Rated cell capacity (1-hour rate)	67 Ah	
Rated cell voltage	3.8 V	
Rated module capacity	2036.8 Wh	
Rated rack capacity	34.6 kWh	24.4 kWh
Number of modules	17 modules	12 modules
Rated rack voltage	516.8 V	364.8 V
Final voltage of rack	435.2 V	307.2 V
Rated discharge current of rack	450 A	
Maximum discharge current of rack*	600 A	
Charge voltage of rack	571.2 V	403.2 V
Charge current of rack	22.3 A	
Temperature	23 ± 5 °C	
Dimensions	W700 × D700 × H2,350 (mm)	W700 × D700 × H1,900 (mm)
Weight	700 kg	600 kg
Electrolyte amount	38.76 L	27.36 L

*Amount of current the battery can produce in 1 second at the time of overload.

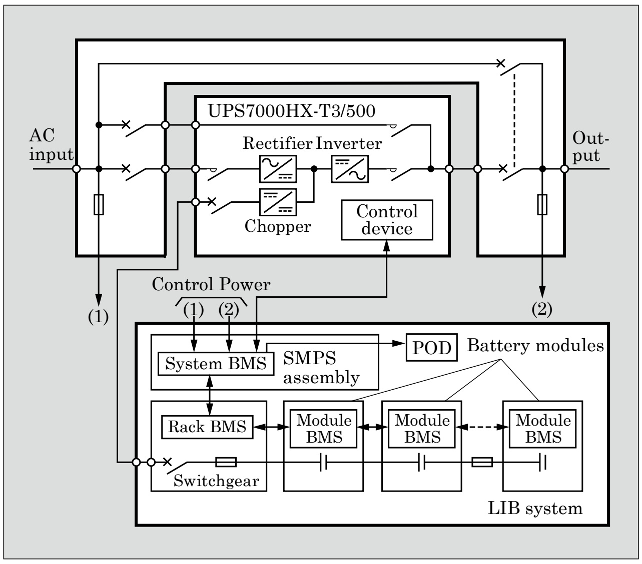


Fig.2 Connection diagram of “UPS7000HX-T3” and LIB unit

modules in the rack. In addition, when an abnormality occurs, it protects the battery system and transmits the rack information to the system BMS, which monitors the rack parallel system.

The SMPS assembly includes a control power supply and a system BMS. The system BMS collects all the information of the rack BMS in the parallel system and transmits the data to the outside via MODBUS*2 communication. The surface of the LIB unit has a liquid crystal display (POD), and the state inside the rack can be monitored. The data can also be stored in an

*2: MODBUS: Trademark or registered trademark of Schneider Automation, Inc.

SD card and used as analysis data.

The battery module has 8 battery cells connected in series. It also has a module BMS inside to monitor the state of the modules. The system measures the cell voltage and the cell temperature and transmits the data to the rack BMS.

The connections between devices, including main circuits and protection circuits, can be performed at the front side, therefore provide good maintainability. The short-circuit protection fuses are in the secondary side of the MCCB (wiring breaker) in the switchgear and in the module section. The control power supply is duplicated and supplied from the input and output of the UPS. The interface with the UPS is only the failure signal of the contact, and the state can be monitored from outside through MODBUS communication.

The rated cell capacity is 67 Ah (1-hour rate), and the rated cell voltage is 3.8 V. The UPS7000HX-T3 includes 17 modules, and the UPS6000DX-T3 includes 12 modules. The rated discharge current per rack is 450 A, and the maximum discharge current is 600 A per second at the time of overload.

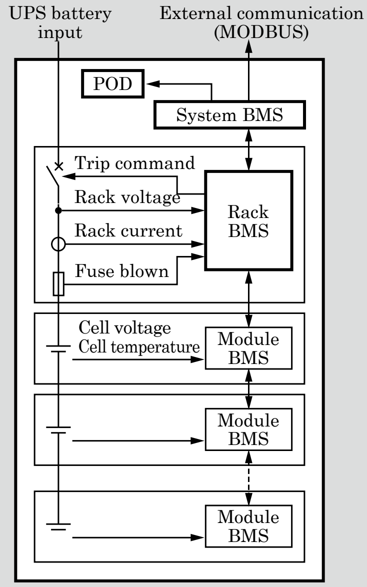
The number of racks necessary for the LIB unit is determined by the backup time of the design lifespan (It does not guarantee the life), UPS capacity, load power factor and DC/AC efficiency with the following conditions as standard: an design lifespan of 15 years, ambient temperature of 25 °C, and discharge condition of a 5% discharge 24 times a year and 100% discharge 2 times a year. Regarding the momentary voltage drop in power systems, it has been reported that the annual average number of momentary voltage drops per substation is 2.8 times. In addition, the duration of momentary voltage drops tends to be 6 cycles or below. This result shows the discharge condition has a sufficient margin.

2.2 Safety of LIB

LIBs have risks of fire and bursts caused by an internal temperature increase due to overcharging or short circuits, and an occurrence need to be prevented. Therefore, measures for preventing accidents are taken for each layer of the LIB cell, the LIB module and the LIB system.

The LIB cell has a structure for preventing short circuits between the anode and the cathode and a safety mechanism regarding temperature increases. In addition, the LIB module has a structure that suppresses temperature increase of cells and uses incombustible materials. The LIB system is also protected in 4 stages: at the UPS, the BMS, the rack fuse and the cell. Figure 3 shows the safety protection of the LIB system. To protect the battery system, the UPS monitors charging overvoltage and undervoltage and trips the MCCB when detecting them.

Table 3 shows the battery system protection function of the LIB unit. There are major failures that release the MCCB and disconnect the Lib system from the UPS, and minor failures that only cause an alarm. The major failures include cell overvoltage, cell undervoltage, rack overvoltage, rack undervoltage, high battery cell temperature, charge overcurrent and discharge overcurrent. The minor failure system moni-



Protection function of battery system

1	BMS monitoring → MCCB trip	Overvoltage/undervoltage Charge overcurrent Discharge overcurrent Cell high temperature
2	Rack protection	MCCB trip Fuse blown
3	Cell protection	Fuse blown in cell Cell protection mechanism Pressure valve release

Fig.3 Safety protection of LIB system

Table 3 Protection function of battery system

Item	Major failure	Minor failure
Cell overvoltage	○	–
Cell undervoltage	○	–
Rack overvoltage	○	–
Rack undervoltage	○	–
Voltage imbalance	–	○
Voltage detection sensing error	–	○
High temperature	○	–
Low temperature	–	○
Temperature unbalance	–	○
Charge overcurrent	○	–
Discharge overcurrent	○	–
Communication failure 1	–	○
Communication failure 2	–	○
MCCB failure 1	–	○
MCCB failure 2	–	○
Current detection abnormality	–	○
Fuse blown	–	○

tors voltage imbalance, low temperature and temperature unbalance, and monitors abnormality of the systems detecting any voltage sensing error, current detection abnormality, communication abnormality and MCCB abnormality. On the other hand, the battery system is protected from short circuit by the fuse in the rack. Furthermore, the cell unit, provided with several protection mechanisms, disconnects abnormal cells from the circuit at the time of overcharging and overheating. The mechanism that lowers the cell's internal pressure (safety valve) operates as a final protection. These protection systems allow safe use.

2.3 Maintenance service

The number of racks is determined with the design lifespan of LIBs as 15 years, but we also provide a capacity guarantee service of 15 years in accordance with the lifespan of the UPS systems. To get the capacity guarantee of 15 years, it is essential that the actual ambient temperature and the discharge conditions meet the specifications. The depth and number of times of discharge has a sufficient margin in comparison with the actual normal blackout, and LIBs are unlikely to be used under the condition exceeding the set discharge conditions. On the other hand, the ambient temperature may change depending on the installation location and arrangement and setting temperature of air conditioners; therefore, temperature monitoring is vitally important. In the case of the capacity guarantee of 15 years, it is necessary to periodically replace the switchgear, SMPS assembly and fuses. Fuji Electric is responsible for performing the maintenance service.

The deterioration of the capacity can be checked by analyzing the data in the BMS.

3. Characteristics of Employed LIB Manufactured by Samsung SDI Co., Ltd

The applications of LIBs and materials of positive electrodes, negative electrodes and electrolytes of LIBs differ by manufacturers. The employed LIB manufactured by Samsung SDI Co., Ltd. consists of a positive electrode made of lithium manganese oxide, which is a composite oxide of lithium transition metal, a graphite negative electrode, and an electrolyte made of a water-insoluble organic solvent. To be used for UPSs, LIBs are required to have high voltage, high energy density and a high discharge rate. The employed LIB has a cell voltage of 3.8 V and an energy density of 135 Wh/kg, which are higher than those of other LIBs, contributing space saving. The LIB also has a rated capacity of 67 Ah and discharge rate*3 of 6C or more, and its 3 to 4 parallel connection system is sufficient for a UPS having a single-unit capacity of 500 kVA. Thus, it is suitable for UPS applications.

The LIBs manufactured by Samsung SDI Co., Ltd are widely used and it has a top share in the usage for automobiles and cellular phones in the global market. They were quickly used for UPS applications also and have been widely used in Asian countries including South Korea since 2011. The LIBs are also low-cost when compared with lead batteries in terms of the life cycle cost of a 15-year design lifespan of UPS systems. Thus, judging comprehensively, we uses the LIB manufactured by Samsung SDI Co., Ltd having a performance suitable for UPS applications, abundant track records, and cost advantages.

4. Advantages and Disadvantages

The following refers to the advantages and disadvantages of LIBs and high-rate discharge lead storage batteries, which have been conventionally used, for UPSs.

4.1 Comparison of battery characteristics

The design lifespan of lead storage batteries is 7 to 9 years. In contrast, LIBs can be used for 15 years and can be replaced at the same time of UPS system replacement. When the capacity of lead storage batteries goes below 80%, the capacity starts to decrease rapidly; therefore, the period for replacing the battery needs to be determined appropriately. However, the capacity of LIBs decreases approximately constantly during the lifetime, and the period for replacing the battery can be determined easily beforehand. LIBs also have good capacity decrease characteristics with respect to temperature. Lead storage batteries follow the Arrhenius' law, and the capacity becomes 50% when the temperature increases by 10 °C. In contrast, when the temperature increases by 10 °C, the capacity of LIBs after 15 years decreases by approximately 10%.

Another significant advantage of using an LIB for UPS is that the discharge capacity that can be taken out is stable. Regarding lead storage batteries, the capacity that can be taken out decreases as the discharge current increases. The capacity that can be taken out also decreases as the temperature decreases. Furthermore, when the discharge current is small, management of final voltage and slow discharge becomes necessary. On the other hand, a capacity decrease due to the difference in discharge current and ambient temperature for LIBs is low.

The disadvantage of LIBs is that the maximum discharge current is lower than that of lead storage batteries. The high-rate discharge lead storage batteries for UPS can supply a large current such as 1.2 C/5 sec. Meanwhile, the maximum discharge current of

*3: Discharge rate: Discharge rate (C rate) = discharge current (A) / battery capacity (Ah). For example, when the capacity is 67 Ah (1-hour rate), the discharge rate of the battery 1 C indicates that the battery discharges for 1 hour at a current of 67 A. Note that C does not indicate a coulomb.

Table 4 Comparison of LIB and high-rate discharge lead storage battery

Items	High-rate discharge lead storage battery	LIB
Capacity	350 Ah (10-hour rate)	201 Ah (1-hour rate)
Design lifespan	7 to 9 years	15 years
Storage unit dimensions	W4,000 × D1,000 × H2,350 (mm)	W2,100 × D700 × H2,350 (mm)
Installation area ratio	100%	53%
Weight	9,600 kg	2,100 kg
Weight ratio	100%	22%

LIBs is 6.7 C.

4.2 Comparison of LIB and high-rate discharge lead storage battery

Table 4 shows the comparison of an LIB and a lead storage battery for high-rate discharge. Conditions during the design lifespan are set as follows: a backup time of 5 minutes, a load capacity of 500 kVA, a power factor of 0.9 and an ambient temperature of 25°C. The number of discharge times was calculated simulating several times of discharge a year for lead storage batteries and a 5% discharge 24 times a year and 100% discharge 2 times a year for LIBs. As a result, LIBs have a footprint ratio of 53% and a weight ratio of 22%, and can save the space needed for an electric room.

5. Safety Measures

The safety standards for LIBs are established in the IEC standards, JIS, and the Electrical Appliance and Material Safety Act. In addition, the UN Recommendations on the Transport of Dangerous Goods stipulates the safety of land, sea and air transportation. In December 2011, "Examination report on the approach to safety measures concerning lithium ion batteries in dangerous facilities" was issued by the Dangerous Goods Safety Office of the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications. To reexamine the fire risks, LIBs were demonstrated and tested for the report in terms of 3 items: the fire risks before and after sealing, safety measures for storage batteries, and safety during storage. On the basis of the result, the approach to safety measures for dangerous facilities that store or handle the LIBs are formulated.

5.1 UN Recommendations on the Transport of Dangerous Goods (UN3480)

The LIBs have passed the safety tests related to battery modules that are specified in UN3480, which are altitude simulation test T1, temperature test T2, vibration test T3, impact test T4 and external short-circuit test T5. In Japan, the LIBs are transported in storage cases that meet a UN standard and the battery modules are installed in the rack on site to stabilize quality.

5.2 IEC standards and JIS

Samsung SDI Co., Ltd has been certified as meeting the international standard IEC 62619 for battery cells, battery modules, and BMS. The test items, conditions and judgment method of JIS C 8715-2, the "Secondary Lithium Cells and Batteries for Use in Industrial Applications," established in 2012 are equivalent to the ones of IEC 62619 as shown in Table 5. Thus, the products conform to JIS C 8715-2. The product is determined to be conforming if it satisfies either of the thermal runaway resistance test and the fire spread resistance test.

Further, it is particularly important to prevent contamination by foreign substances during a cell process. An internal short-circuit test assuming contamination by foreign substances is specified. In the internal short-circuit resistance test, a charged single cell is disassembled, and a nickel piece is placed between the separator and the positive electrode active material at the outermost periphery or between the separator and the negative electrode active material. The test piece is then verified whether the initial voltage drops by 50 mV or more while being pressurized in a pressurizing device. In this test, Samsung SDI Co., Ltd has confirmed that it does not drop voltage and does not cause internal short circuit even when pressurizing up to 400 N.

5.3 Electrical Appliances and Materials Safety Act

In 2008, the Order for Enforcement of the Electrical Appliances and Materials Safety Act was revised, and LIBs that meet certain requirements came to be subject to the Electrical Appliances and Materials Safety Act. This standard has the same test items as IEC 62133 (JIS C 8712 stipulates similar safety standards as IEC 62133) and JIS C 8714 have. The volume density of the LIB per cell is 261 Wh/L, which is

Table 5 Comparison of JIS C 8715-2 and IEC 62619

Applicable	JIS C 8715-2	IEC 62619
Cell	External short-circuit test	External short-circuit test
	Impact test	Impact test
	Drop test	Drop test
	Thermal abuse test	Thermal abuse test
	Overcharge test	Overcharge test
	Forced discharge test	Forced discharge test
	Thermal runaway resistance test	Internal short-circuit
System	Fire spread resistance test	–
	Overcharge control of voltage	Overcharge control of voltage
	Overcharge control of current	Overcharge control of current
	Overheating control	Overheating control

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smaller than 400 Wh/L, and the LIB is not subject to this Act.

5.4 Handling of LIB under the current Fire Services Act

The electrolytes of LIBs correspond to water-insoluble substances that fall into dangerous goods class IV second oil division, and the quantity is specified to be 1,000 L. The electrolytes also need to conform to the technical standards of dangerous materials stipulated in the government ordinance. For dangerous materials of less than specified quantity, storing or handling must follow the fire prevention ordinance of each municipality.

5.5 Safety measures for dangerous facilities that store or handle LIBs

The safety measures related to the storage and handling of storage batteries are stipulated as follows on the basis of the fact that the fire risk is greatly reduced by the UN Recommendations on the Transport of Dangerous Goods, the Electrical Appliances and Materials Safety Act, IEC standards and JIS, and certain knowledge has been obtained by experiments.

When a storage battery meets the following (1) to (2), it is not necessary to take the following measures:

(1) Impact test (limited to storage batteries that are not subject to the Electrical Appliance and Material Safety Act) specified in T4 of the United Nations Recommendation (UN 3480) 38.3,

Or, safety is secured against the external burden by crushing test prescribed in the Electrical Appliance and Material Safety Act.

(2) In case of leakage or flammable vapors are not confirmed from the inside of the storage battery in the drop test from the height of 3 m.

The LIB is conforming because it passed the recommendation of the United Nations and the 3-m drop test. Therefore, the LIB does not have to meet the following requirement for dangerous facilities or the small-amount dangerous facilities that store or handle liquid dangerous materials.

(a) The electrical equipment shall have an explosion-proof construction.
(b) Floors shall have structure that doesn't allow hazardous substances to permeate, and the floor shall be inclined and fitted with a collection drain (a catch-basin).
(c) Equipment shall be installed for discharging flammable vapor and particulates outside from a high position.

5.6 Regulation on storage of dangerous materials according to use districts

For buildings that store and process dangerous materials, the Building Standards Act stipulates "unit regulation" associated with securing fire prevention safety of the building itself and "use regulation" associated with geographical conditions. The City Planning Act and the Building Standards Act are provided with a use district designation system for creating a good urban environment and securing functional urban activities by appropriately arranging residential, commercial and industrial districts in the city. This system determines land use as a general framework of residential, commercial and industrial urban areas. The use districts are classified into 12 types, and a restriction is imposed for each use district. The LIB corresponds to dangerous materials to be subject to the use regulation, and it is necessary to keep the restricted amount of storage in accordance with the use district. According to this, it is permitted to store 50 times the specified quantity in quasi-industrial districts, 10 times the specified quantity in commercial districts, and 5 times the specified quantity in quasi-residential districts.

The general LIB capacity of the UPS7000HX Series and the UPS6000DX Series is below the above restricted amount of storage, and the products are not subject to the regulation.

6. Postscript

The "UPS7000HX Series" and "UPS6000DX Series" having lithium ion batteries have been described. The UPS conform to safety standards and regulations related to dangerous material storage. Thus, we would like to offer these UPSs to data centers to contribute to their space saving. We will be expanding the applications to overseas projects and medium-capacity UPSs of 100 kVA or lower.

References

(1) Yamagata, Y. et al. "UPS 7000HX Series" of High-Efficiency, Large-CapacityUPS Products Using AT-NPC 3-Level for Data Centers. FUJI ELECTRIC REVIEW. 2012, vol.58, no.4, p.207-211.

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