Electrical Energy Storage Devices & Systems

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Expectations of renewable energy as a measure to solve the issues of global warming and energy resource shortage are increasing. However, concerns over the unstabilization of power grids are growing, as the amount of wind power and photovoltaic energy sources—the generating power of which fluctuates intensely—increases, and stabilizing the electrical power grid is becoming important issue. On the other hand, experiences of long-term blackouts and following electricity shortages and restrictions after the Great East Japan Earthquake have increased awareness of the need for power source decentralization and high-level energy management for further stable electric power supply and energy conservation. Electrical energy storage systems are expected to increase their important roles as key facilities to solve the above issues. In this paper, products and technologies of four electrical energy storage devices & systems contributing to energy storage systems and energy conservation of various types of energy managing equipment are overviewed.

1 Introduction

In recent years, more and more phenomena have seen sparking grave concerns over influences due to the steady progress of global warming, such as frequent abnormal weather worldwide. As an ace card to counter global warming, the widespread use of renewable energy sources is expected, such as wind and solar power. It is also becoming more important to utilize renewable energy from the viewpoint of energy security, given the increasing scarcity of fossil fuels, which is set to be exacerbated by growing demand for energy resources following economic growth in developing countries. Although many countries have been promoting the introduction of renewable energies, concerns are rising over the unstabilization of power grids caused by increased wind power and photovoltaic (PV) energy sources—the generating power of which fluctuates intensely depending on weather conditions. As a countermeasure, the importance of mitigating fluctuations in output power and stabilizing power grids by introducing electrical energy storage systems is becoming prominent.

On the other hand, experiences of long-term blackouts and following electricity shortages and restrictions after the Great East Japan Earthquake have increased the interest in having a stable power supply and boosted awareness of the needs for power source decentralization, secure energy supply near demand area, and high-level energy management, particularly electric power for further energy conservation; not only during emergencies but also under normal circumstance. Various efforts to improve over all energy efficiency by introducing high-level energy management systems into a range of areas, such as house, building, factory, commercial facility or community, and networking power using equipments with electrical energy storage systems are already underway. The market for electrical energy storage systems is expected to further proliferate, not only as emergency power sources but also key facilities of energy management.

Continuing actions to conserve energy and reduce carbon dioxide emissions have further intensified. Since automobiles are considered a major carbon dioxide emission source, a target of around 30% additional reduction of fuel consumption regulation value for 2020 compared to the 2014 figure is under consideration for developed countries, including Europe, Japan and North America[1)], while the introduction of fuel economy standards comparable to those in developed countries is also being considered for developing countries such as China. Various electrification systems and systems to enhance power-train efficiency for better fuel efficiency are also predicted in future.

To realize a low-carbon society, a comprehensive approach will be required encompassing expanding the use of renewable energy and boosting the efficiency of existing facilities on the supply side, and striving to conserve energy from both hardware/software perspectives on the demand side, i.e. not only technological energy saving for devices and systems, but also savings in electric power and energy by changing consumer behavior. In this paper, our electrical energy storage devices/system products which help save energy in hardware perspective and technologies to support these products are introduced.

2 Possessed Technologies and Products

In April 2012, the Hitachi Chemical group took over Shin-Kobe Electric Machinery Co., Ltd. as a wholly owned subsidiary to further enhance our electrical energy storage device & system business. Its research and development division was also subsequently integrated. Thanks to this merger, we are promoting the development of highly competitive products; supported by fusing superior key technologies such as electrical energy storage device development/ manufacturing technology owned by Shin-Kobe Electric Machinery and the basic technology such as material development, evaluation & analysis cultivated ever since our company was founded.

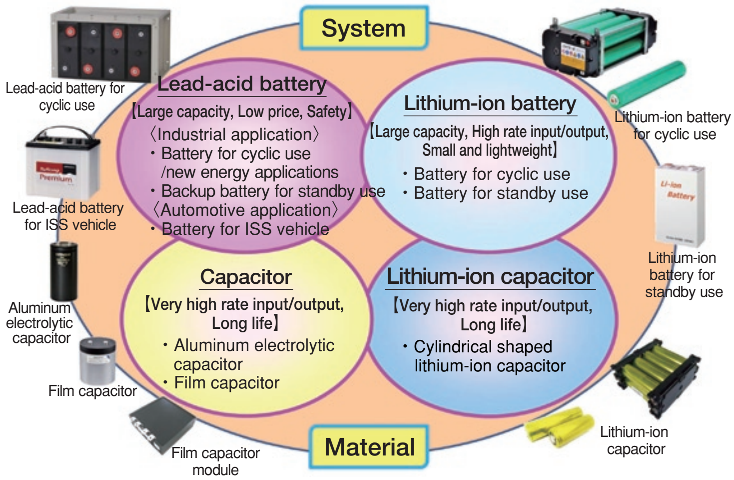


Figure 1 Four electrical energy storage device businesses at Hitachi Chemical

One outstanding feature of our business portfolio is the fact that our company deploys four distinctive electrical energy storage device businesses (lead-acid battery, lithium-ion battery, lithium-ion capacitor and capacitor) as well as owning critical materials to improve the performance of these devices and system technology and products best placed to exploit each device. We set our sights on accelerating development and expanding business; backed by mutual cooperation and a synergy effect (Figure 1). Our company's approach to device and system fields are introduced separately below.

2.1 Lead-acid Batteries for Automotive Applications

Our lead-acid battery business is deployed for automotive and industrial applications, and in this section lead-acid batteries for automotive applications are introduced. To reduce carbon dioxide emissions, various measures and technical developments to improve fuel efficiency are being spearheaded, mainly by automobile manufacturers, such as methods to improve fuel combustion, reduce car body weight and downsize in conventional internal-combustion engine automobiles (with gasoline and diesel engines) as well as changing drive systems e.g. in hybrid, pure electric and fuel-cell vehicles. Although hybrid cars have significantly improved their fuel efficiency, they remain costly, so we predict that they will be limited to Japan and North America in the immediate future. As for internal-combustion engine automobiles, which we expect will continue to comprise the majority auto market share, automobiles with ISS (idling stop system) are increasingly attracting attention. ISS can only be implemented by redesigning certain parts such as electric generator, starter and lead-acid battery. However, it boosts fuel efficiency and economy, hence our prediction that sales of ISS-equipped automobiles will expand, mainly in Europe and developing countries, and exceed 35 million automobiles (5 times the current sales volume) by 2020, comprising 30% of total global automobile sales[2]. Automobiles with ISS frequently stop and start engines while awaiting traffic signal changes, supply electric power from the battery to electrical components while the engine is shut off, and enable swift electric power regeneration-type charging using high-powered alternators during traveling. Lead-acid batteries, meanwhile, are prone to be insufficient charging state due to frequent short-term charging and large discharge. Accordingly, there is a need to enhance the regenerative charging efficiency during deceleration to properly exploit the ISS advantage, namely for a high-performance lead-acid battery with charge acceptance performance enabling an efficient time-effective charge and high durability to withstand repeated charging and discharging. In light cars greater fuel efficiency improvements are obtained with ISS, however batteries mounted in such cars require particularly high performance due to the restriction of the size from limited installation space.

In 2006, our company was first to develop[3] a lead-acid battery with a high charge acceptance performance for automobiles equipped with alternator regenerative control as a kind of environmentally friendly vehicle (reducing engine load and improving fuel efficiency by controlling alternator operation). Leveraging this lead-acid battery, a first-generation battery for passenger cars with ISS was developed in 2010, followed by an enhanced second-generation battery for light cars in 2011[4, 5]. The charge acceptance performance of conventional battery for general vehicle and first/second-generation batteries for automobiles with ISS are compared in Figure 2, and their cyclic durability performances are compared in Figure 3. To improve the charge acceptance performance, the rate-limiting charge reaction at negative electrode should be accelerated. In response, we engaged in development focusing on organic additives and carbon for negative electrodes. We also promoted design improvements for each generation, including efforts to optimize active materials for positive electrodes and reduce the resistance of electrode grid. Consequently, the charge acceptance performance of second-generation batteries was approximately doubled compared to the performance of our conventional battery for general vehicles. For second-generation lead-acid batteries, new carbon additive, with electrical conductivity enhanced to ten times the level for general vehicles was employed for negative electrodes. Durability was also boosted

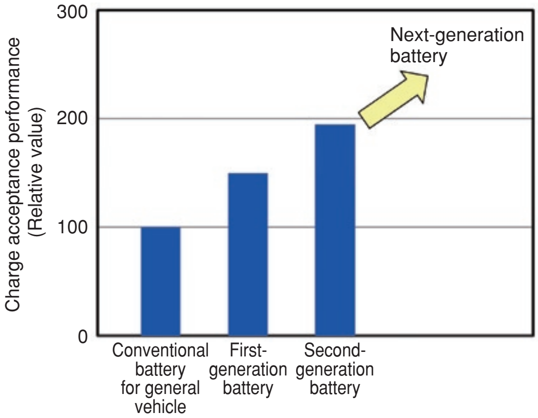


Figure 2 Comparison of charge acceptance performance between conventional and developed batteries (Relative value, based on the value of conventional battery as 100)

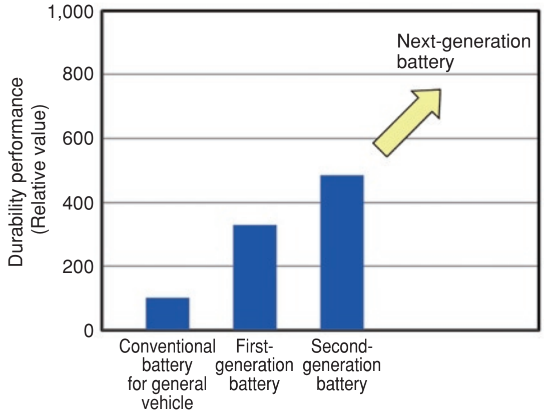


Figure 3 Comparison of durability between conventional and developed batteries (Relative value, based on the value of conventional battery as 100)

around fivefold thanks to successful suppression of stratification (phenomenon of differential concentration between upper and lower layers in the electrolyte solution) and sulfation (accumulation of lead sulfate). These improved high-performance paved the way for us to commercialize lead-acid batteries which can be mounted in light cars allowing battery use under severe conditions of requiring a depth of discharge exceeding 10% compared to passenger cars[5]. We will continue the ongoing development of new technologies, including new separator structures (see details in this technical report) to further improve battery performance.

A lead-acid battery is a device with a chemical reaction integral to the performance development, for which controlling the cell reaction by materials is key. As for development of the above mensioned negative electrode additives, we sought materials which could be controlled to optimize the configuration and physical properties of products involved in the charge/discharge reaction of negative active materials, which significantly impact on battery performance. During this research works, we elucidated[6] the effect of additives and the effect-inducement mechanism by observing morphological change in the active material during the charge/discharge reaction directly *in-situ* and the electrical conductivity of reaction products by atomic force microscopy (AFM), in cooperation with Hitachi Research Laboratory, Hitachi, Ltd. Figure 4 shows examples[3] of observations, revealing clear differences in the amount and configuration of lead sulfate ($PbSO_4$) and lead (Pb), caused by the difference of additives. The elucidation of mechanisms and product development could eventually be accelerated, allowing changes of material on the same place to be observed on the spot, while the effect of additives could also be confirmed more clearly. As for the development of organic additives, we will continue to further improve lead-acid battery performance by developing works backed up by synergistic effects between our groups, such as linkage with material design techniques using quantum chemical calculations and material synthesis/analysis techniques owned by our material group.

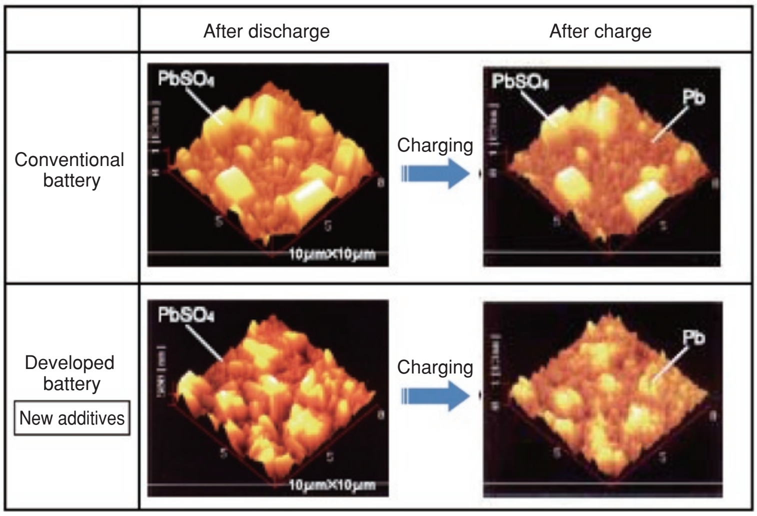


Figure 4 Images of *in-situ* AFM observations which visualize changes in morphology among electrode active materials during charge-discharge cycles

For automotive systems, we foresee progressive applications of advanced driver assistance systems such as collision avoidance for high safety and self-driving as well as efforts to date to improve fuel efficiency. Meanwhile, we must be ready to accommodate increased demand for electric power and secure redundancy where problems affect the electrical supply. We will continue striving in future, as well as to increase storage capacity and improve the reliability of our lead-acid batteries, to search for other possibilities such as innovative lead-acid batteries with significantly improved performance and hybridization with other power sources such as lithium-ion capacitors.

2.2 Lead-acid Batteries for Industrial Applications

In the field of lead-acid batteries for industrial applications, we are marketing our products by focusing on applications to back up the power source for important social infrastructure such as hospitals, public facilities, fixed and mobile base stations, data centers and power stations as well as offices and factories to date, leveraging advantages such as low price, safe, large capacity

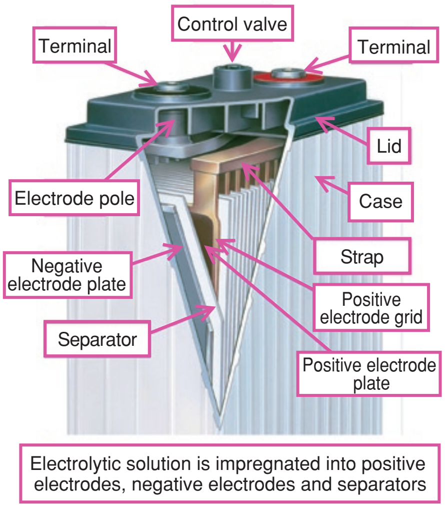
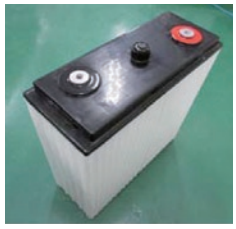


Figure 5 Structure of valve-regulated lead-acid battery

Table 1 Comparison of specifications and appearances between LL1500-WS (new product) and LL1500-W

		LL1500-WS (new product)	LL1500-W
Single battery	Photos of exterior appearance		
	Number of terminals	Positive electrodes: 3 Negative electrodes: 3	Positive electrodes: 1 Negative electrodes: 1
	Nominal voltage-nominal capacity	2 V−1,500 Ah (10 HR, 25℃)	
	Maximum discharge current	900 A	600 A
	Maximum charge current	450 A	300 A
Expected life*1		17 years for the application to mitigate fluctuation (25℃) [4,500 cycles at 70% depth of discharge]	
Example system*	1 MW×1 h discharge	Battery capacity 3.8 MWh	Battery capacity 4.6 MWh
	1 MW×0.5 h discharge	Battery capacity 3.1 MWh	Battery capacity 4.6 MWh

*A representative example, and its performance level may vary depending on specification details and operating conditions.

and easy operation of lead-acid batteries. In addition, we are enhancing and expanding our business in the field of cyclic use applications such as electrical energy storage systems, which store surplus electric power overnight and discharge it during peak daytime hours, electrical load leveling (peak shaving/shifting) and mitigating fluctuations in output power from renewable energy power generators. For these applications, valve-regulated lead-acid batteries are used by exploiting the advantage of long life, high reliability and low maintenance requirement of elimination of water-refilling. In this section, we introduce our approaches to improve the valve-regulated lead acid battery by extending its life and enhancing its product performance in cyclic use.

Conventional valve-regulated lead acid batteries for standby use were difficult to use for cyclic use applications due to the short cycle life of 200 to 500 charge/discharge cycles. Accordingly, we developed the LL series[7] batteries for electrical energy storage applications with an expected life*1 of 3,000 cycles by significantly improving cycle life performance in 2001. In 2005, we developed[9] the LL-S series[8] extending the expected life of 4,500 cycles, followed in 2009 by the LL-W series batteries with an expected life (industry-wide longest life*2) of 17 years for applications to mitigate output power fluctuations from renewable energy generators.

The structure of the valve-regulated lead-acid battery is shown in Figure 5. During the aforementioned development, we achieved the extension of life by undertaking various measures, not only improvement of the main battery components such as the active materials used for positive and negative electrodes, reviewed the alloy composition and shape design of the positive grid, and optimized the specifications of the electrolytes and separator but also optimizing the battery-charging condition, horizontal placement of the electrode plate (see the top-left photo of the lead-acid battery module for cyclic use in Figure 1) and improving materials for the durable battery housing (case and lid) sufficiently to extended life[7)-12)]. Moreover, in September 2014, we could successfully commercialize[13] a high rate charge/discharge cycle performance type battery of the LL1500-WS series, the charge/discharge performance of which became 1.5 times higher than LL1500-W without impairing the long life by reviewing the structure of the battery terminal and strap electrodes, and suppressing heat generation and decline in voltage during the high-current discharge. The characteristics of the LL1500-WS are compared to LL1500-W in Table 1. As the system example shows, a higher performance, that is higher discharge current per battery unit, can be met for systems requiring a high current discharge within a short time with fewer batteries, and realize more economical, compact and lighter battery units. We will also continue work to develop and further enhance battery performance and expand applications for large capacity lead-acid batteries.

During developments to extend life and enhance performance as aforementioned, electrode design technology realizing the suppression of corrosion deformation of positive electrode grids and heat generation at straps, poles and terminals by design optimization was one of the key technologies. Our company has been promoting CAE (Computer Aided Engineering) to design electrodes; targeting design sophistication and reduced designing periods in cooperation with Hitachi Research Laboratory, Hitachi, Ltd. This eventually spawned our unique simulation technology which is capable of predicting the current collection properties (voltage drop, current distribution) on grids, the corrosion deformation of electrode grids, and even manufacturability (molten metal flow, solidification) of designed grids during the casting process[12), 14)]. Figure 6 compares the simulated and actual corrosion deformation results of positive electrode grids, faithfully reproducing curvature deformation and the degree of

*1 Expected life: Life estimated under our recommended operating conditions
*2 Industry-wide longest life: as end of August 2014 and as per our survey

deformation of exterior frame grids. This helped expedite the design optimization of electrode grids and accelerate product development.

The deterioration modes of lead-acid batteries differ depending on service conditions, such as backup applications where batteries await while fully charged (standby), cyclic applications where batteries undergo frequent and repeated charging/discharging, and the same cyclic applications but to store electrical energy and mitigate fluctuations in output power. For example, when mitigating fluctuation of output power from wind power generators, batteries must remain in a state of charge acceptance to respond to fluctuating generated power. Accordingly, this means batteries for cyclic applications are used only in partially (rather than fully) charged state, imposing very severe service condition for the use of lead-acid batteries. When improving performance in terms of extending the battery life, robust deterioration analysis and prediction based on both research & analysis of batteries with long-term actual operation results and simulation tests assuming various operation modes will be important, and it will be crucial to accumulate these data and this expertise. Our group have already been delivered these products to wind power generating plants for use in mitigating fluctuations of output power since 2002[9), 15)] and many data have been accumulated in this field. Our group will continue developing distinctive products by sophisticating service life prediction technique using these accumulated database.

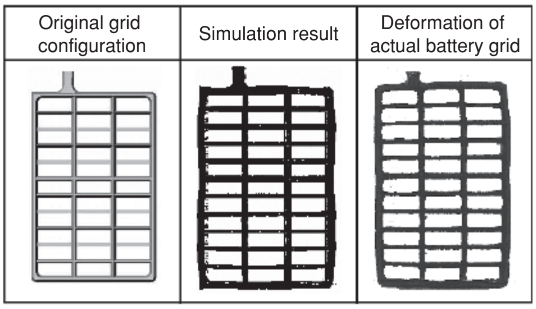


Figure 6 Simulation result of the corrosion deformation of a positive electrode grid compared with the deformation of an actual battery grid

2.3 Lithium-Ion Batteries for Industrial Applications

The lithium-ion battery can be featured for small and light weight, large capacity and high rate input/output, and it is widely used primarily for small consumer devices. Similarly, in automotive applications, the lithium-ion battery has achieved full-scale practical and widespread use for various environmentally-friendly vehicles in response to increasing environmental awareness and alongside the demand for high fuel efficiency. Conversely, as for industrial applications, the market for lithium-ion batteries is expected to grow in terms of future applications for power supply backup during emergencies, drive /energy regeneration for railroad vehicles and other industrial machines, load leveling, mitigation of output power fluctuations from renewable energy generator and power grid stabilization.

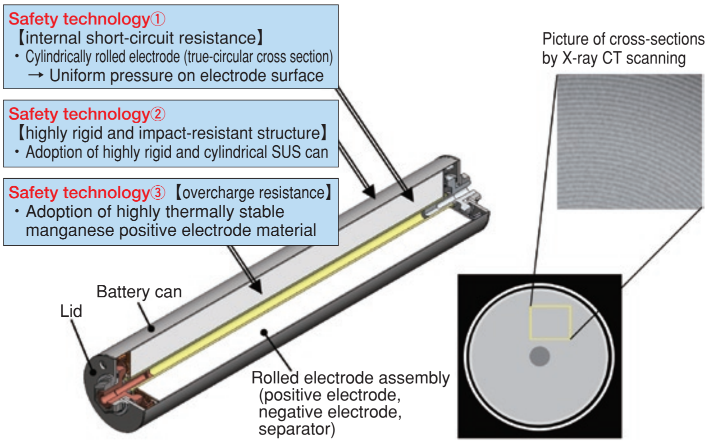
We have been promoting a lithium-ion battery business targeting industrial applications and focusing on two types of battery in the device development process. One of which is for cyclic use applications, featuring repeated charge/discharge cycles and the other is for standby (backup) power supply in emergencies, involving waiting for extended periods in a fully charged state. Our lithium-ion battery can be characterized by its design, which satisfies both large capacity and safety/reliability. Thanks to its large unit cell capacity (single battery); the required cell number can be reduced to form the intended system capacity. This means the total parts count, including peripheral components, can be dramatically reduced and allows overall system reliability to be improved.

As for batteries for cyclic use applications, to date, we have developed lithium-ion batteries used for electric vehicles (EV) and hybrid vehicles (HEV) in cooperation with Hitachi, Ltd. and succeeded in commercial vehicle applications as a world first[16)-18)] in 2000. In 2004, development and manufacturing operations of lithium-ion batteries for automotive applications were transferred to Hitachi Vehicle Energy, Ltd., a joint company established by Hitachi, Ltd., Hitachi Maxell, Ltd. and Shin-Kobe Electric Machinery, Ltd. and we have been engaged in developing large-capacity batteries for industrial applications from 2009. We are developing batteries characterized by their large size & cylindrical shape; a configuration nurtured over many years of battery development for automobiles. On this occasion, we developed a new type of lithium-ion battery CH75, which shows excellent safety, high output power and an extended cycle life, even if its ampere-hour capacity is as large as 75 Ah. The specifications of our developed CH75 cell and its exterior photo are shown in Table 2, with three main technical points to enhance safety (Figure 7). The first was the adoption of cylindrical geometry and the true-circular cross-sectional shape of rolled electrode assembly, which helped ensure uniform pressure distribution over the electrode surface and eliminate internal short-circuit factors caused by hetero-structure, thereby increasing internal short-circuit resistance. Furthermore, this structure can reduce the strain caused by expansion and contraction of the electrode during repetitive charging and discharging cycles and the CH75 realizes the expected 10,000 cycle life[*1]. As a second point, the CH75 was built in a highly rigid cylindrical SUS can, which may prevent expansion during battery operation and provide a highly reliable structure, less prone to damage from external impact. The third point was the adoption of manganese positive electrode material, which shows excellent heat stability and thanks to which a battery capable of meeting safety requirements for industrial-use lithium-ion batteries (JIS C8715-2) could be developed. This CH75 was mounted into the 1 MW container-type electrical energy storage system “CrystEna” developed by Hitachi, Ltd. and verification tests of the ancillary (frequency regulation) service in the power grid stabilization project in the North America are underway[19)].

In recent years, with larger information and communication capacity at higher speed, the power consumption of communication equipment and the electricity required to emergency power supplies for these facilities have increased. Conversely, it has also become increasingly difficult to expand electrical energy storage systems using lead-acid batteries due

Table 2 Specifications and appearance of a lithium-ion battery CH75 cell for cyclic use

Battery		CH75	Photo of exterior appearance
Nominal voltage		3.7 V	
Nominal capacity		75 Ah	
Current	Discharge	Continuous：225 A Maximum：300 A	
	Charge	225 A	
Weight		Approx. 3 kg	
Dimension		Φ 67×410 mm	
Expected life*1		10,000 cycles	



(a) Model cross-sectional drawing in an axial direction (b) Model cross-sectional drawing along the radial direction of a cell

Figure 7 Safety technologies of a lithium-ion battery CH75 cell

to the limited installation space in urban data centers, based on which the compact lithium-ion battery with high volume energy density has emerged as a promising replacement. Data center requirements for emergency backup on a large scale with higher current for about 10 minutes in emergencies have also emerged, with increased amounts of data until the emergency generator starts to operate. The KL200 lithium-ion battery, with capacity of 200 Ah (expected life*1:10 years)[20] was developed for long-term high-capacity backup power systems, while a new TH100 battery, capable of rapidly discharging high electric current, was developed for short-term high-current backup power systems.

Since batteries have always been used in their fully charged state for standby (backup) use applications, we have to assume certain circumstances for lithium-ion batteries leading to thermal runaway caused by internal short circuits or overcharging due to charging device malfunctions, however remote the possibility. Further emergency power supply apparatus is often installed inside buildings in urban areas, for which high-level safety should be required. In this context, working alongside NTT FACILITIES, INC., we have been engaged in flame retardation of electrolytes as a safety technology and to develop lithium-ion batteries for use in standby applications. During this development process, we faced a major technical challenge in balancing flame retardation with extended life. We developed[21] a self-extinguishing electrolyte equivalent to UL94-V0*3 by adding phosphazene flame retardants to flammable organic electrolyte for flame retardation. Lithium-ion batteries have been primarily used for cyclic applications and research into standby applications has been insufficient. It is a known fact[22] that the capacity of a fully charged lithium-ion battery deteriorates over time if left unattended. Accordingly, we conducted a detailed analysis of the capacity deterioration mechanism and successfully balanced an extended life with non-flammability through measures including improving the manganese positive electrode active material and using new electrolyte composition[20]. When developing the TH100, we achieved both high-current discharge performance and an extended life by reducing electrode resistance, increasing the amount of electrical conductive material in the positive electrode and thinning the electrode, thus enabling rapid high-current discharge. The specifications of the cell and a photo of the exterior appearance are shown in Table 3. TH100 is a large safe battery with 100 Ah capacity, capable of continuous discharging at a maximum current of 500 A for 10 minutes or more.

Table 3 Specifications and appearance of a lithium-ion battery TH100 cell for standby use

Battery	TH100	Photo of exterior appearance
Nominal voltage	3.7 V	
Nominal capacity	100 Ah	
Maximum discharge current	500 A	
Weight	Approx. 7 kg	
Dimension	153×255×72 mm	
Expected life*1	7 years	

2.4 Lithium-ion Capacitors

The lithium-ion capacitor is an electrical energy storage device with a positive electrode structure of electric double-layer capacitor and a negative electrode structure of lithium-ion battery[23], characterized by (1) higher operating voltage and higher energy density compared to an electric double-layer capacitor and (2) higher output power density compared to a lithium-ion battery and capable of rapid charge/discharge (high power input/output), (3) capable of one million or more charge/discharge cycles (100% in charging depth at room temperature) (long service life), (4) low self-discharge and (5) high-level safety[24]. By exploiting these features, lithium-ion capacitors are steadily coming into use aiming for main power sources, regenerating power and stabilizing

*3 UL94-V0: Material and product safety standards issued by Underwriters Laboratories Inc. to determine flame retardation of resin. "V0 is a class of flame retardant which self-extinguishes less than 10 seconds after removing the flame". As there were no flame retardation standards for batteries, we evaluated this by referring to the standards for resin.

electric power in industrial applications such as automatic guided vehicles (AGVs), stacker cranes[25], construction machines[26] and instantaneous voltage drop compensators[27]. Furthermore, power system stabilization technology using lithium-ion capacitors is being studied to suppress short cycle output power fluctuations from wind power and solar power (PV) generators and deployment to regeneration applications for environmentally-friendly vehicles as a global warming countermeasure in future is expected.

We mass-produced a lithium-ion capacitor featuring a large cylindrical shape in the name of LCAP based on our technologies developed for the lithium-ion battery (see previous section) in October 2009[28]. The lithium-ion must be pre-charged (pre-doped) in the negative electrode during the LCAP manufacturing process. To mass-produce LCAP, we established a technique for pre-charging large-sized cylindrical cells by applying our long-cultivated battery manufacturing technology and successfully achieved commercial production. LCAP shows excellent performance such as high vibration and impact resistance to withstand the harsh vibrations to which construction equipment is subject in operating environments, effective heat resistance at high temperatures and no swelling deformation by overcharging/discharging thanks to its cylindrical structure, true-circular rolled electrode assembly and rigid steel can. We have continued to improve the performance, including capacitance and DC resistance reduction following the aforementioned successful commercialization and our current products are characterized in Table 4.

Table 4 Specifications and appearances of lithium-ion capacitors/LCAP

Item	SLC-B110A	SLC-B152A	Photos of exterior appearance
Operating voltage range	2.2～3.8 V		
Operating temperature range	−15～80℃		
Capacitance	1200 F	2000 F	
DC resistance (actual value)	2.0 mΩ	1.6 mΩ	
Dimension	Φ 40×110 mm	Φ 40×152 mm	
Weight	270 g	350 g	

We are developing LCAP monitoring circuit board, packs (modules/packages of multiple cells and monitoring circuit board) and cubicles (electrical energy storage battery boards storing multiple packs and control circuit) by utilizing control and packaging technologies refined through our lithium-ion battery and lead-acid battery development[29, 30]. Representative examples of packs and cubicle are shown in Figure 8. (a) shows a holder-type pack with eight series connected cells, while (b) shows the exterior of a box-type pack containing 40 series connected cells in which 5 sets of 8-cell packs, and a cell controller capable of detecting voltage and temperature, compensating for voltage variation between cells and reporting abnormalities to the host system. (c) shows the inside of a cubicle developed for large capacity electrical energy storage systems, whereby 12 packs of 40 series connected cells described in (b) are mounted inside in four serial and three parallel configurations. This cubicle also mounts a battery management unit, which allows integration of information from cell controllers and reporting the LCAP status to the host system. This cubicle includes a delivery record in applications to mitigate output power fluctuations from solar power (PV) generation.

(a) Holder-type pack

(b) Box-type pack

(c) Cubicle interior photo

Figure 8 Examples of developed LCAP packs and cubicle

2.5 Capacitors

The capacitor features a structure with dielectric material inserted between opposed electrodes and is a passive component, which temporarily stores an electrical charge by utilizing the polarization phenomenon while electrical voltage is applied to electrodes. The amount of stored energy involved is less than a battery because it is not accompanied by electrochemical reactions seen in batteries, but the capacitor is a device capable of short-term cyclic charges/discharges and instantaneous large current discharge (high input/output power, long life).

Accordingly, the capacitor has a feature to pass alternating current and not to pass direct current, making it indispensable to share an important role in an electrical circuit to eliminate high frequency noise, transmit signals, and suppress voltage variance and leveling. In recent years, rapid shifting to power electronics/inverter has been underway in various application field in response to reduced power consumption and improved efficiency, and DC capacitors are used as key components for these inverter-control circuit. Such capacitors share the role of eliminating ripple current (pulsating current) and noise superimposed on direct current and further suppressing voltage fluctuation at instantaneous voltage drop by storing electrical charges; which requires high breakdown voltage, large capacity and excellent ripple current dulability.

Our business development efforts have been focused on aluminum electrolytic capacitors and film capacitors. In this section,

we introduce the characteristics and technologies of our capacitors, focusing on high-voltage large-capacity aluminum electrolytic capacitors and film capacitors, which are applicable for the high-voltage inverter-control circuit used in new energy devices such as wind power and solar power (PV) generators, environmentally-friendly cars, railroad vehicles and industrial equipments.

A cross-sectional structure of the aluminum electrolytic capacitor is shown in Figure 9. It has a structure with aluminum metallic film as the positive electrode and an anodic oxide film (Al_2O_3) formed on the surface of the positive electrode as its dielectric material, and the thinner the anodic oxide film and the larger the surface area, the higher the electrical energy storage performance. Its dielectric material is a thin film 0.5 to 0.8 µm thick and with breakdown voltage of about 700 V/µm. The surface area has also increased 20 to 40 times due to the micro-textured concave and convex surface patterns achieved by etching; realizing a capacitor with large electrical energy storage capacity per unit volume. Suppressing heat generation by ripple current is a key to improving ripple current dulability. To realize downsizing (a larger capacity per unit volume) and the excellent ripple current dulability of aluminum electrolytic capacitor as required, we have reduced internal resistance and improved[31] the heat dissipation performance of capacitors via surface area expansion thanks to an improved etching technique, modification of the dielectric oxide film, reducing the resistance of electrolytic solution and reviewing the packaging configuration of capacitor elements in a case. Trends of our capacitor performance improvements are shown in Figure 10. Ripple current dulability was more than doubled and approximately 30% downsizing was achieved over the past 20 years.

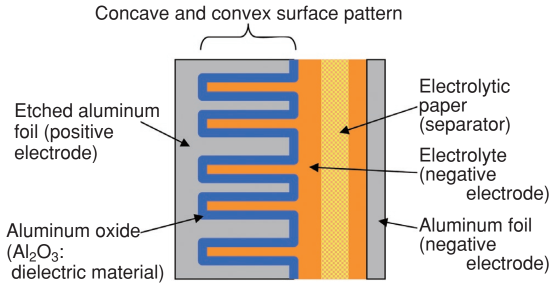


Figure 9 Schematic cross-section of an aluminum electrolytic capacitor

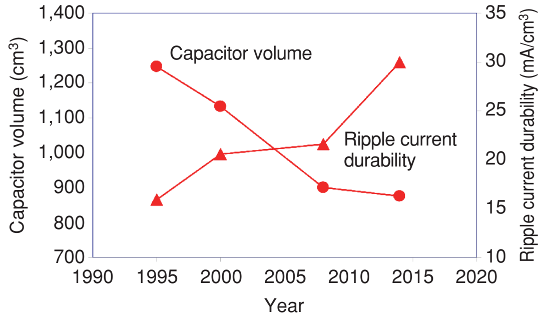


Figure 10 Volume and ripple current durability change of our screw terminal type aluminum electrolytic capacitors (rated voltage of 450 V, 6800 µF)

The film capacitor is using plastic film such as polypropylene (PP) as a dielectric material and features a rolled-up structure of the aforementioned film on which vapor-deposited metals such as aluminum is formed as a electrode (Figure 11). It is characterized by its high breakdown voltage compared to aluminum electrolytic capacitors and small amount of self-heating due to low dielectric loss and small capacitance change by temperature, frequency, etc., which extends its life[32]. We have increased the breakdown voltage, reduced internal resistance and boosted the ripple current dulability by optimizing a vapor-deposited electrode design capable of providing a self-repairing (self-healing) and a self-protection properties, improving device fabrication techniques, such as reducing the stress during film winding process and forming collector electrode (metalicon) and improving the device storing and wiring configuration in the housing[33), 34)]. Figure 12 shows photos of the typical exterior appearance of (a) the cylindrical metal case type and (b) module type products developed as high-voltage large-capacity capacitors. The module type of (b) is a capacitor module containing parallel connected assembly of multiple rolled-up film capacitor elements, in a resin case and resin-sealed[34)].

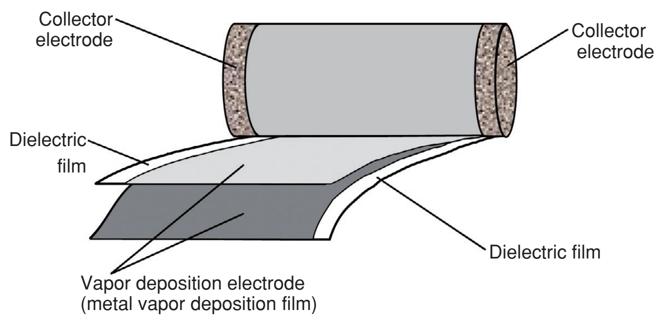


Figure 11 Structure of metallized film capacitor element

(a) 116 Φ Cylindrical metal case-type

(b) 300□Module-type

Figure 12 High voltage & large-capacity film capacitors for power electronics applications: (a) cylindrical metal case type, (b) module type capacitor array

2.6 Electrical Energy Storage Systems

We have developed various electrical energy storage systems, including emergency power supplies, systems for load leveling (peak shaving/peak shifting) (brand name: Sefla system), regenerated energy storage systems[35)] to reuse regenerative electric power from cranes and transportation vehicles and systems to stabilize power grid by utilizing various in-house electrical energy storage devices. The Sefla system is an electrical energy storage system combining lead-acid batteries or lithium-ion batteries with

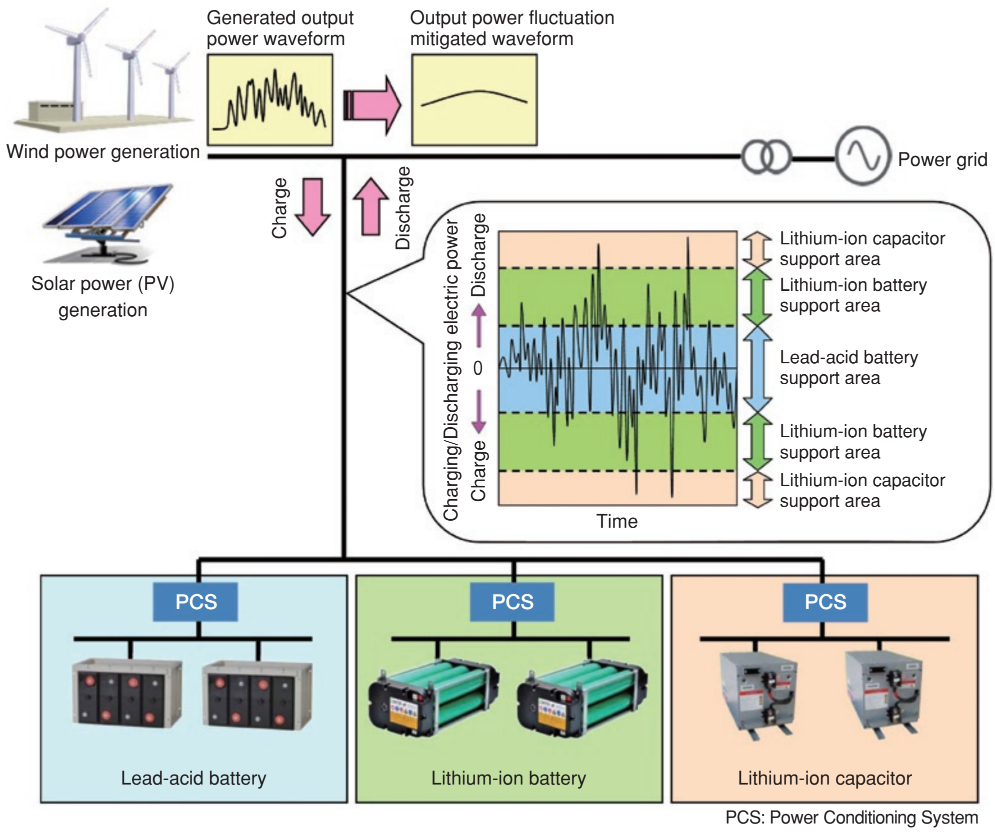


Figure 13 Conceptual diagram of hybrid type electrical energy storage system

a power conditioning system (PCS) capable of shaving the demand power peak in daytime by discharging electrical energy stored overnight and simultaneously facilitating countermeasures to maintain Business Continuity Planning (BCP) as an emergency power supply[36), 37)].

In recent years, the capacity of electrical energy storage systems has become larger-scale; for example, there are 10 MWh and a few MWh level capacities for lead-acid and lithium-ion batteries respectively[38)]. Various requirements are imposed based on the various objectives of use and electrical energy storage system applications, which means responding to such requirements with a single type of energy storage device may not always be appropriate. Each electrical energy storage device has its own unique characteristics and combining multiple types of such devices allows systems to be optimized. We are also considering practical applications of such hybrid electrical energy storage systems, thus ensuring we can offer solutions which balance performance, cost and size by exploiting the performance characteristics of each device. The concept of the hybrid electrical energy storage system is shown in Figure 13. When mitigating output power fluctuations from wind power generators, for example, mitigation of both long- and short-term cycle fluctuations is required. By using both an inexpensive lead-acid battery with excellent relatively slow charging/discharging performance to mitigate long-term cycle fluctuations and a lithium-ion battery or capacitor with excellent fast charging/discharging performance to mitigate short-term cycle fluctuations, downsizing the system and reducing cost is easier to achieve compared to a system configured by a single type of energy storage device. Designing a hybrid electrical energy storage system requires an optimum combination by taking the performance characteristics of each device fully into account. Accordingly, we developed a design tool taking the performance characteristics of various energy storage devices into consideration (refer to this technical report for details of hybrid electrical energy storage systems).

For the operation of electrical energy storage systems, it is important to ensure proper control status of the batteries [chargeable/dischargeable power, state of charge (SOC), temperature, etc.]. As the electrical energy storage system is becoming larger scale and more widespread, the requirement for efficient maintenance has become more urgent. There is a number of issues to be solved; for example, the status of each battery is periodically confirmed by human hands or even if monitoring sensors were mounted on each battery to improve monitoring efficiency, the wired system needed numerous wires, which hindered efforts to ensure the system reliability. We have placed the monitoring system of many batteries into practical applications by measuring the status of each battery with remote wireless slave units and sending data to a master unit[39)] or via the Internet[37)].

3 Conclusion

Electrical energy storage device and system products are a group of products which share important roles in comprising infrastructure for a secure and safe society by delivering a steady supply of electricity and achieving a low carbon society. We prioritize environment & energy fields as key business areas and promote our electrical energy storage business.

While we will continue to further improve the performance of each device by developing new technology, economic rationality should also be satisfied for bussiness expansion. Accordingly, we must continue our product development efforts to reduce costs and extend life. We will continue to actively engage in wide-ranging cooperation with internal and external organizations with relevant interests to accelerate our product and application development. We intend to deploy a wide range of product groups and solutions, ranging from materials to devices, right up to systems and services and pledge to follow through with our corporate philosophy, namely "Contribute to society through the development of superior technologies and products that can herald a new era."

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