

# Energy Storage Solutions Utilizing Lithium-ion Batteries

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*OVERVIEW: Concern for the global environment and the desire to use energy more efficiently are driving growing demand for lithium-ion batteries in industrial applications as well as in consumer products and automobiles. Application of lithium-ion batteries in industry requires the technical skills to be able to use them correctly and this in turn requires a good understanding not only of the batteries but also of the equipment and systems (load) to which power is being supplied. In addition to the batteries themselves, Hitachi has an extensive involvement with a wide range of products and systems such as power plants that act as the loads in these systems. Hitachi is taking advantage of this technical background to lead the world in commercializing these industrial systems.*

## INTRODUCTION

INITIATIVES for reducing CO<sub>2</sub> (carbon dioxide) emissions triggered adoption of measures to deal with global climate change and progress is being made in areas such as making efficient use of fossil fuel sources and the installation of new energy sources such as solar and wind power, while signs are also emerging of growing adoption of electric vehicles. Against this background, there is growing demand for and recognition of the major benefits of storing electric energy.

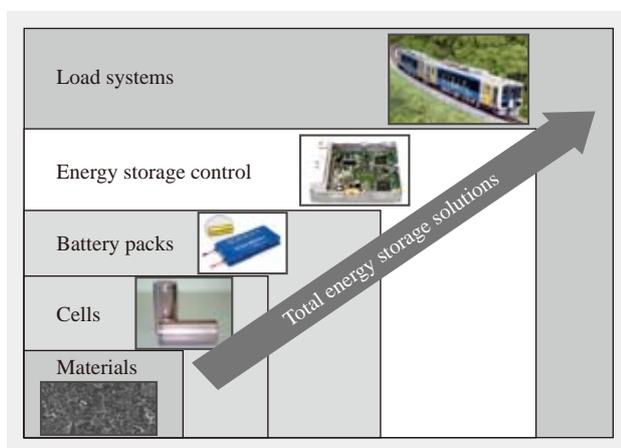
Electricity is an energy source in which production (generation) and consumption take place in parallel, and the spatial and temporal restrictions on its use are significant, including the difficulty of energy storage

and necessity for transmission lines. Providing a way around these restrictions is the primary function of batteries and recent improvements in the output and capacity of lithium-ion batteries have reached a level where they are now adequate to answer these needs. What is required to make this a reality is the technology to utilize lithium-ion batteries in energy storage solutions that satisfy the social requirements described above.

This article describes the importance of knowledge and experience of the systems and equipment that act as the load when implementing energy storage solutions, specific technologies possessed by Hitachi that relate to lithium-ion batteries, and examples of how these have been put into practice.

## HITACHI'S COMPREHENSIVE STRENGTH IN ENERGY STORAGE SOLUTIONS

Using lithium-ion batteries, which have a cell voltage of approximately 3.7 V, to produce the voltage and current required by the systems and equipment (load) being supplied involves the use of assembled batteries in which multiple cells are arranged in series and parallel. In this case, the battery properties and the load system characteristics and behavior are important design considerations. Hitachi is well placed to design optimum energy storage solutions with experience in the design and manufacture of products ranging from electrodes and other lithium-ion battery materials to cells, battery packs, and energy storage control systems, as well as the systems and solutions that form the load (see Fig. 1).



*Fig. 1—Total Solutions for Energy Storage. Because the energy storage control system sits between the battery cells and load systems, an understanding of both is required to design optimum solutions.*

## APPLICATION OF LITHIUM-ION BATTERIES

Maintaining the performance and long life of an assembled battery is not simply a matter of connecting lithium-ion battery cells in series and parallel to achieve the required voltage, current, and power. Instead, understanding the behavior of the load as well as the resulting charging and discharging behavior and then designing a battery system specific to those requirements has a major influence on the system's performance and lifetime. Systems based on lithium-ion batteries behave in an analog way and significant experience and know-how is required for their successful application.

Industrial energy storage involves voltages, currents,

and other output parameters that are considerably larger than those of mobile phones and other consumer products and this makes the development of industrial systems extremely difficult. Understanding the load system is of particular importance during design and this represents the starting point for development as well as being the most important factor in achieving an optimum design.

As a general electrical manufacturer, Hitachi has experience in supplying a range of different electrical machinery, systems, and solutions; and through the development, design, and production of these products has acquired a deep familiarity with load systems. It is able to draw on this know-how to supply optimum battery systems (see Fig. 2 and Fig. 3).

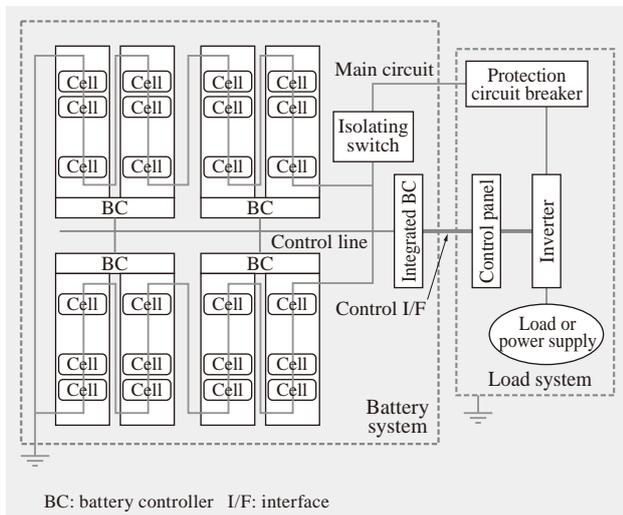


Fig. 2—Idealized Load and Battery Systems. The battery system and control scheme are determined based on an understanding of the load (or power source) connected via an inverter.

## HITACHI TECHNOLOGIES THAT SUPPORT ENERGY STORAGE SOLUTIONS

Although an understanding of the load system is essential to the optimum design of lithium-ion battery systems, the individual technologies that go into lithium-ion batteries also have a significant influence on their value as a product. The following sections describe the most important of these technologies.

### Materials Technology

Hitachi operates an integrated process of materials development for lithium-ion batteries extending from synthesis of electrode materials to testing and evaluation. In addition to undertaking testing of newly developed materials utilizing its comprehensive capabilities for the analysis of electrode interfacial reactions and degradation mechanisms, Hitachi is also working on developing lithium-ion battery cells with even better performance.

### Lithium-ion Batteries

Hitachi has a range of different lithium-ion batteries for industrial applications, extending from batteries for hybrid cars where the emphasis is on output through to float charging batteries for backup power supplies where capacity is the main consideration (see Fig. 4).

### Control ICs for Lithium-ion Batteries

Lithium-ion batteries require protection circuits to protect the battery cells from damage by over-current, overcharging, or over-discharging. Protection circuit products developed by Hitachi include various control ICs (integrated circuits) ranging from models for single cells through to models for notebook PCs (personal

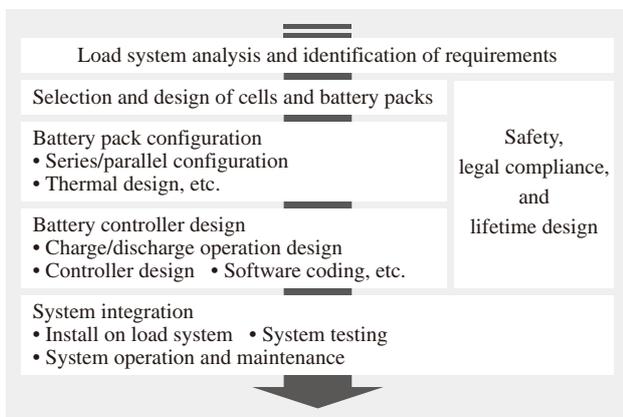


Fig. 3—Flow Chart of Energy Storage System Engineering. The conventional sequence of engineering steps is with underlying consideration of safety and legal compliance as well as lifetime design.



Fig. 4—Examples of Lithium-ion Batteries.  
Examples of lithium-ion batteries produced by Hitachi Group companies for industrial applications.

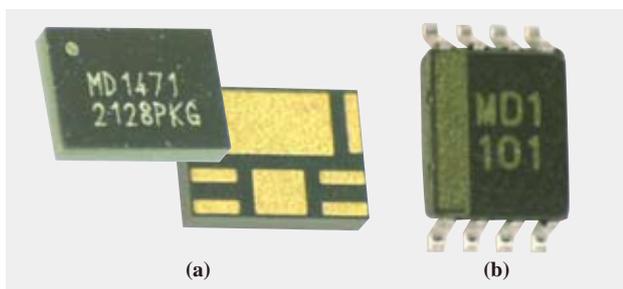


Fig. 5—Examples of Control ICs (made by Hitachi ULSI Systems Co., Ltd.).  
The (a) is an MD1471 2-in-1 [monitoring IC (integrated circuit) + FET (field-effect transistor)] single-cell series-connected IC and the (b) is an MD1101 IC for three or four series-connected cells [for PC (personal computer) battery packs].

computers) that manage multiple cells connected in series, and also monitoring ICs for battery cells used in products such as electric power tools (see Fig. 5).

Hitachi also develops specialist ICs for the high-voltage lithium-ion battery packs required by hybrid vehicle powertrains which incorporate large numbers of cells connected in series.

### Battery Controllers

Industrial battery systems are configured by connecting a number of battery packs in series or

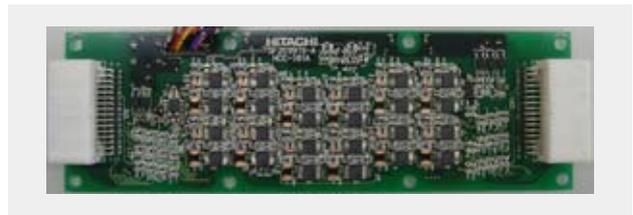


Fig. 6—Battery Controller for Hybrid Vehicle Battery Pack.  
This battery controller manages a single battery pack which is made up of a number of cells connected in series. The controller uses a special-purpose control IC and its functions include individual battery voltage detection, temperature detection, overcharging/over-discharging/over-temperature detection, balancing, and communications.



Fig. 7—Integrated Battery Controller for Hybrid Vehicle Battery System.  
This integrated battery controller manages a set of battery packs that are connected together. Its functions include measurement of overall voltage, current, and temperature; calculation of remaining power level, level of degradation, and permitted current; monitoring and protection (voltage, current, temperature, and electrical leakage); temperature management; charger control; history management; and communications.

parallel, and these battery packs in turn are made up of cells connected in series with the number of cells being determined by the power, voltage, and current requirements of the load system. The control that maintains a good balance across the cells by monitoring the charge/discharge status of each is also an important factor. It is also necessary to provide a way of supplying this information to the load system so that it can modify its operation accordingly. The unit that handles these tasks is called the battery controller (see Fig. 6 and Fig. 7).

Hitachi has produced models to suit various different applications by using a battery controller designed to manage the individual battery packs in a hybrid vehicle as a base and enhancing it to create an integrated battery controller that manages a set of battery packs connected in series and parallel.

### Applications Combined in a Knowledge-base

Hitachi works with a wide range of products and systems ranging from nuclear, thermal, hydro, wind, and other power plants through to systems in which trains, building systems, or hybrid vehicles and machinery act as the load, and the knowledge and experience gleaned from these provide the basis of Hitachi's technical capabilities for implementing optimum energy storage solutions. Although these systems and products are handled by various different business units within Hitachi, research departments, operational departments, and sales departments work together in an organic way to form a huge knowledge-base that can focus this knowledge and experience on finding the solutions to problems (see Fig. 8).

### EXAMPLE ENERGY STORAGE SOLUTIONS

#### Battery System for Hybrid Vehicles

Hitachi formed Hitachi Vehicle Energy, Ltd. in 2004 to develop and produce automotive lithium-ion batteries and the company proceeded to undertake technical and manufacturing developments covering everything from materials to battery controllers that have led the world in bringing lithium-ion batteries for hybrid vehicles to market. The company's main product at present is its second generation battery. This assembled battery made up of cells that use a manganese-based positive electrode (cathode) and amorphous carbon for the negative electrode (anode) has achieved sales to date of 1.2 million cells and demonstrated high reliability and long life [see Fig. 9 (a)].

Hitachi Vehicle Energy's lithium-ion batteries are not only used in hybrid cars, but also in railway systems which also require high reliability and long life and have similar requirements for repetitive short-duration transitions between power and braking (electric regeneration).

#### Hybrid Locomotive

More efficient use of energy and better environmental performance are also requirements for trains and hybrid operation is increasingly being adopted in diesel trains that run on non-electrified tracks as a means of recovering braking energy and operating the engine in its most efficient speed range. Hitachi became the first company in the world to commercialize this technology when it won an order from the East Japan Railway Company to supply hybrid drive systems for its Kiha E200 Type locomotives.

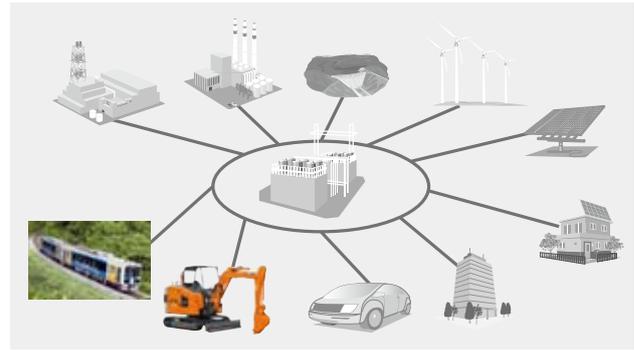


Fig. 8—Comprehensive Hitachi Capabilities that Support Energy Storage Solutions.

Hitachi products span all aspects of electric power from generation to consumption. The ability to store electric energy is required in many of these applications creating opportunities to utilize lithium-ion batteries.

The lithium-ion batteries used in the system were second generation models from Hitachi Vehicle Energy. The scope of the project covered more than just installing the system and a full program of evaluation and testing of the powertrain was conducted beforehand to determine the behavior of the system installed in a locomotive under traction, freewheeling, and braking (regeneration) conditions. This can be seen as an example of an application where knowledge and experience of railway systems proved very important [see Fig. 9 (b)].



Fig. 9—Industrial Applications of Lithium-ion Batteries. Examples of industrial applications for Hitachi lithium-ion batteries are found in various industries.

## Electrical Conversion System for Trains Incorporating Electricity Storage

Because the distance between stations serviced by suburban electric trains is often short resulting in frequent alternation between traction and braking, these trains have long made use of the regenerative energy produced during braking. To provide a means of making effective use of this regenerative energy even when there is no nearby train in traction mode that can use the regenerated energy, and also to stabilize the feeder line voltage, Hitachi developed and supplied the regenerative power battery storage system that uses lithium-ion batteries. The development utilized Hitachi's integrated railway power system simulator to perform a full evaluation of the effectiveness of an electric regeneration system with a storage capability and to design an optimum system. The possession of various technologies including electric trains, railway operation management, and feeder line conversion systems together with an understanding of how the overall electric power supply infrastructure operates as a system were essential elements in the successful commercialization of this product [see Fig. 9 (c)].

## Battery-powered Compact Excavator

Because of the need to protect the environment around the work site, the field of construction machinery sometimes comes under strong pressure to deal with problems of noise and engine exhaust. Contractors may also be called on to take specific measures to reduce CO<sub>2</sub> emissions to comply with the policies of their clients. To meet these needs, Hitachi Construction Machinery Co., Ltd. has developed and commercialized a lithium-ion battery shovel that supplies power to its actuators from internal lithium-ion batteries instead of from the engine. Models in the 7-t and 5-t classes have been available since 2006 and a 3.5-t class model capable of extended operating time was released in late 2010. The battery systems were developed jointly by Hitachi Construction Machinery and Shin-Kobe Electric Machinery Co., Ltd. [see Fig. 9 (d)].

## CONCLUSIONS

This article has described the importance of knowledge and experience of the systems and equipment that form the load when implementing energy storage solutions, specific technologies possessed by Hitachi that relate to lithium-ion batteries, and examples of how these have been put into practice.

It is anticipated that future use of lithium-ion batteries in power supply systems will not be limited to only those cases described above but will extend to a wide range of different applications. An important factor in this will be the broad-based technical capabilities needed to apply lithium-ion batteries effectively. Hitachi, Ltd.'s Battery Systems Company established an Engineering Department on August 1, 2010 with a mission to utilize the comprehensive strengths of Hitachi in applications for lithium-ion batteries and to supply these as solutions to customers. This division will take a central role in coordinating the relevant Hitachi business units to create a range of new solutions that meet customer needs.

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