Title: INTEGRATED DROP-IN LITHIUM BATTERY SUBSTITUTE FOR LEAD-ACID BATTERIES

Abstract: A lithium battery system provides electrical characteristics comparable to electrical characteristics of a lead-acid battery. The system includes at least one lithium battery cell and electronics including a voltage converter. The voltage converter is coupled to an output of the Li cell and converters the output of the lithium cell to an electrical output characteristic of a lead-acid battery.
INTEGRATED DROP-IN LITHIUM BATTERY SUBSTITUTE FOR LEAD-ACID BATTERIES

FIELD OF THE INVENTION

[0001] The invention relates to lithium battery systems having voltage shaping circuitry designed to mimic the electrical behavior of lead acid batteries.

BACKGROUND

[0002] Lead acid batteries have proliferated into thousands of consumer and commercial products in the marketplace. Users have become accustomed to the electrical behavior and size and shape of sealed lead-acid batteries in products ranging from medical infusion pumps, neighborhood scooters, and computer battery backup un-interruptible power supplies.

[0003] The available battery form factors, configurations, and integration for lead acid batteries are standardized across the industry. Charging and maintenance electronics for lead-acid batteries are also highly developed and inexpensive. However, the calendar life, cycle life, maintenance cost, and weight of lead acid batteries are limiting factors in their overall usefulness. Many users of systems which include lead-acid batteries are desirous of an alternative battery that would overcome one or more of these limitations.

[0004] A battery system provided by Valence Technology Inc., Austin, TX provides a lithium ion replacement for a 12V lead acid battery packed in standard lead acid sizes. However, based on the voltage curves provided, there is clearly no voltage shaping electronics provided to mimic the electrical behavior of a lead acid battery. Therefore, the lithium ion replacement for a 12V lead acid battery provided by Valence Technology Inc. may have the right size and shape for lead acid replacement, but the electrical characteristics remain that of a lithium battery.
SUMMARY OF THE INVENTION

[0005] A lithium battery system provides electrical characteristics comparable to electrical characteristics of a lead acid battery. The system includes at least one lithium battery cell and electronics including a voltage converter. The voltage converter is coupled to an output of the Li cell and converts the output of the lithium cell to an electrical output characteristic of a lead-acid battery. The voltage converter can comprise a bidirectional switching converter.

[0006] The system can further comprise electronics coupled to the Li cell for monitoring and managing the cell, the electronics having structure for providing at least one selected from the group consisting of charge control, overcharge protection, discharge protection, and cell equalization. An outer case is preferably provide, wherein the lithium battery cell and the electronics are disposed in the outer case, where the outer case has a size and shape of standard lead acid batteries.

[0007] A single lithium cell can be used which after (boost) conversion provides 12 to 14 Volts 25 °C. In another embodiment, 3 cells are used, with the voltage converter again comprises a voltage boost converter. In another embodiment, 4 cells are used and the voltage converter comprises a voltage buck converter.

[0008] A method of substituting a lithium battery for a lead-acid battery, comprises the steps of providing a lithium battery system comprising at least one lithium battery cell and electronics including a voltage converter, the voltage converter coupled to an output of the Li cell, and converting the output of the lithium cell using the voltage converter to an electrical output characteristic of a lead-acid battery. The lithium battery system preferably includes an outer case, wherein said lithium battery cell and said electronics are disposed in the case, wherein the case
provides a size and shape characteristic of a lead acid battery. The method can further comprise the step of installing the battery system in a system specified for a lead acid battery.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] A fuller understanding of the present invention and the features and benefits thereof will be obtained upon review of the following detailed description together with the accompanying drawings, in which:

[0010] Fig. 1 shows an exemplary packaged Li battery system including a voltage converter which is designed to be a drop-in substitute for a lead acid battery, according to an embodiment of the invention.

[0011] Fig. 2 shows voltage discharge curves for a conventional 6-cell lead-acid battery as compared to the discharge curve of an unconverted single Li cell.

[0012] Fig. 3 shows a discharge voltage comparison illustrating the results from boosting a single 5Ah Lithium cell according to the invention with a constant boost to match the output voltage of a standard 2 Ah 12V lead-acid battery.

[0013] Fig. 4 shows a discharge voltage comparison illustrating the results from boosting a single 5Ah Lithium cell according to the invention with a variable boost to more closely match the output voltage of a standard 2 Ah 12V lead-acid battery as compared to the constant boost result shown in Fig. 3.

DETAILED DESCRIPTION OF THE INVENTION

[0014] A lithium battery system which provides electrical characteristics comparable to a lead acid battery comprises at least one lithium battery cell, and a voltage converter. The voltage
converter is coupled to an output of the Li cell and converts the output of the Li cell to electrical characteristics of a lead-acid battery. The inventive battery system thus replaces an industry-
standard lead-acid battery with a drop-in lithium battery that in a preferred embodiment requires no changes to the form factor, configuration, or system integration. As used herein the phrase "converts the output of the Li cell to electrical characteristics of a lead-acid battery" is defined as making the output voltage from the lithium battery system match the output voltage of the lead acid battery (for a given application) within 10%, preferably within 5%, and most preferably within 2% over the complete discharge curve. Matching the entire voltage vs. state of charge (SOC) thus meets system requirements that use voltage as a signal, such as for low battery alarms that use voltage as the trigger.

[0015] The invention is applicable to all Li battery types, including, but not limited to Li metal, Li ion and Li polymer batteries. Although generally described for converting electrical characteristics of lithium batteries to that of lead acid batteries, more generally, the invention allows one battery type to provide the electrical characteristics of another battery type.

[0016] In a preferred embodiment of the invention the lithium battery system is a packaged system including an outer case that is of the same size and shape of industry-standard lead-acid batteries. Inside the case there is at least one lithium battery cell, electronics to monitor and manage the lithium battery cell(s), electronics to provide the necessary voltage boost to match the lithium battery cell(s) to the standard lead-acid interface, thus allowing the lithium battery to be a direct replacement for the lead-acid battery in the application.

[0017] Figure 1 shows an exemplary packaged battery system 100 according to an embodiment of the invention. A plurality of lithium battery cells 101 are configured in series and/or parallel inside of the case 102, the cell number and configuration depending on the
desired electrical properties. Although described as being a plurality of cells, there may also be just one lithium battery cell in system 100. Electronics 103 monitors and manages the lithium cells 101 by preferably providing charge control, overcharge protection, discharge protection, cell equalization, and other standard safety and maintenance functions. These functions, if desired to be in addition to standard lead acid battery capabilities, include are State of Health (SOH) algorithms, State of Charge (SOC) algorithms, and thermal monitoring and protection circuits. These functions can be communicated outside the battery to a host device. Electronics 103 also generally include memory, such as for storing characteristic voltage curve data of a lead acid battery for a given application, structure for measuring battery current output, its state of charge, and resistance as a function of the state of charge.

[0018] Microprocessor-based management electronics for these functions are well known in the art. Beginning in the 1990s, some battery modules have included logic chips (either microcontrollers or programmed custom logic chips). These chips are commonly referred to as "Smart Battery Modules" which have been used for charge/discharge control, communications, and related functions such as overtemperature and overcurrent monitoring, or for a "gas gauge" function which estimates battery life. For example, United States Patent No. 5,929,606 to Faulk entitled "Ripple-suppressed converting battery module" discloses a universal battery pack which contains an integral DC-DC switching power converter, with an asymmetric ripple-suppression topology which suppresses ripple at the power output terminals during discharging is an exemplary smart battery module that can be used with the invention. United States Patent No. 5,929,606 to Faulk is incorporated by reference into the present application.

[0019] The electronics according to the invention is preferably, but not required to be, chip-based. One function of electronics 103 is for converting the standard lead-acid charging voltages
to voltages acceptable for charging lithium cells. In reverse, the electronics 103 convert the
discharge voltage of the lithium cells to the standard discharge voltage of lead-acid batteries.
[0020] System also up-integrates the cell or plurality of cells 101 to the standard lead-acid
interface. System 100 includes a bi-directional DC-DC switching voltage converter 104 for this
purpose, which may be of the buck, boost, buck-boost, cuk, flyback, forward, or other known
converter topology. Electronics 103 and converter 104 can be combined into a single device.
The output of voltage converter 104 is provided across terminals 108 and and 109, which are
standard for lead acid batteries.
[0021] The voltage converter 104 takes the voltage curve obtained from a lithium battery 201
shown in Figure 2 and “maps” its voltage to the voltage curve characteristic of a lead-acid
battery 202. The characteristic voltage curve of the lead acid battery is generally pre-
programmed into the electronics 103. Data for the characteristic voltage curve can be obtained
by measuring output characteristics of a lead acid battery in a given application (having a certain
load) or by calculating the output characteristics using known equations for lead acid batteries.
[0022] The unmapped lithium battery voltage may be more or less than the standard lead-
acid battery voltage level. Depending on the number of cells and the voltage converter 104 used,
the lithium voltage provided will be “boosted” to match the standard lead-acid level, or “bucked”
to match the standard lead-acid level.
[0023] For example, a conventional automobile operates at 13.6V nominal, the voltage being
set by a standard 6-cell lead acid automobile battery in the automobile. The nominal lithium
voltage for standard automotive application is either 10.9V (3 cells) or 14.6V (4 cells). If the
lead acid battery is replaced by a 3 cell lithium battery, the voltage will be too low. If the lead
acid battery is replaced by a 4 cell lithium battery, the voltage will be too high. Electronics
provided systems according to the invention can adapt the voltage of the lithium battery up or down to 13.6V, to match the original specification of the automobile.

[0024] Figure 3 provides data showing a discharge voltage comparison illustrating the results of boosting a single 5Ah lithium cell by a constant factor of 3.5 X according to the invention 301 to match the output voltage of a standard Yuasa (Yuasa Battery, Inc. Reading, PA) 2 Ah lead-acid battery 302. The Yuasa specifications include a valve regulated sealed lead acid battery, 12 Volt, 2 Ah, Dimensions: L 148mm x W 20mm x H 90mm having standard blade terminals. Better results (not shown) can be obtained by varying the boost factor as a function of time to more closely match the lead acid discharge curve.

[0025] In a preferred embodiment a variable level voltage conversion is performed. Figure 4 shows a discharge voltage comparison illustrating the results from boosting a single 5Ah Lithium cell according to the invention 401 with a variable boost level. It can be seen that the variable boost level more closely matches the output voltage of the standard 2 Ah 12V lead-acid battery 302 by comparing the results shown in Fig. 4 as compared to the results shown in Fig. 3.

[0026] The invention may be used in applications for systems that require nominal lead acid voltages. There exists a large market of lead acid batteries in which regular replacements are required. The invention allows lithium battery systems to displace lead acid batteries during these replacement cycles.

[0027] It is to be understood that while the invention has been described in conjunction with the preferred specific embodiments thereof, that the foregoing description as well as the examples which follow are intended to illustrate and not limit the scope of the invention. Other aspects, advantages and modifications within the scope of the invention will be apparent to those skilled in the art to which the invention pertains.
CLAIMS

We claim:

1. A lithium battery system providing electrical characteristics comparable to electrical characteristics of a lead acid battery, comprising:

   at least one lithium battery cell and electronics including a voltage converter, said voltage converter coupled to an output of said Li cell, said voltage converter converting said output of said lithium cell to electrical output characteristics of a lead-acid battery.

2. The system of claim 1, wherein said voltage converter comprises a bidirectional switching converter.

3. The system of claim 1, further comprising electronics coupled to said Li cell for monitoring and managing said cell, said electronics having structure for providing at least one selected from the group consisting of charge control, overcharge protection, discharge protection, and cell equalization.

4. The system of claim 1, further comprising an outer case, wherein said lithium battery cell and said electronics are disposed in said outer case, said outer case having a size and shape of standard lead acid batteries.

5. The system of claim 1, wherein said at least one lithium battery cell is a single lithium cell, said single lithium cell after voltage conversion providing 12 to 14 Volts 25 °C.
6. The system of claim 1, wherein said at least one lithium battery cell consists of 3 of said cells, said voltage converter comprising a voltage boost converter.

7. The system of claim 1, wherein said at least one lithium battery cell consists of 4 of said cells, said voltage converter comprising a voltage buck converter.

8. A method of substituting a lithium battery for a lead-acid battery, comprising the steps of:

   providing a lithium battery system comprising at least one lithium battery cell and electronics including a voltage converter, said voltage converter coupled to an output of said Li cell, and

   converting said output of said lithium cell using said voltage converter to an electrical output characteristic of a lead-acid battery.

9. The method of claim 8, wherein said lithium battery system includes an outer case, wherein said lithium battery cell and said electronics are disposed in said case, said case providing a size and shape characteristic of a lead acid battery.

10. The method of claim 9, further comprising the step of installing said battery system in a system specified for a lead acid battery.
Discharge Voltage Comparison

- Lead Acid Discharge Curve
- Lithium Discharge Curve
- Full Charge
- 202
- 201
- Single Lithium Cell Voltage

Time (Hours:Min)

0:00:00 1:00:00 2:00:00 3:00:00 4:00:00 5:00:00 6:00:00 7:00:00 8:00:00 9:00:00 10:00:00 11:00:00 12:00:00

FIG. 2
**Discharge Voltage Comparison**

- **Boosted Lithium Discharge Curve**
- **Lead Acid Discharge Curve**

**FIG. 4**