The present invention discloses a method and a device for controlling battery heating. The method may comprise the following steps: starting battery heating when conditions for starting battery heating are met; and stopping battery heating when conditions for stopping battery heating are met. The conditions for stopping battery heating may be at least one of the following: (a) an absorbed energy of the battery reaching a predetermined energy; (b) a period of time during which a discharging current of the battery maintains constant reaching a predetermined period of time; (c) the discharging current starting to decrease; or a heating time reaching a maximum heating time. The method and the device according to the present invention consider a plurality of conditions including temperature, discharging current, battery SOC and heating time etc., to determine battery heating, which may meet requirements of the practical applicabilities and may not damage the battery with enhanced battery lifespan.

**Fig. 1**

![Flowchart of Method and Device for Controlling Battery Heating](image-url)
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SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, ML, MR, NE, SN, TD, TG).
METHOD AND DEVICE FOR CONTROLLING BATTERY HEATING

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of:

(a) Chinese Patent Application Serial No.200910147356.7 filed with the State Intellectual Property Office of the P. R. China on June 18, 2009,

(b) Chinese Patent Application Serial No.200910147355.2 filed with the State Intellectual Property Office of the P. R. China on June 18, 2009, and

(c) Chinese Patent Application Serial No.200910147362.2 filed with the State Intellectual Property Office of the P. R. China on June 18, 2009,

the entire contents of which are all incorporated herein by reference.

FIELD

The present invention relates to battery temperature management, more particularly to a method and a device for controlling battery heating.

BACKGROUND

Currently, lithium ion batteries have become an ideal power supply for portable electronic devices and electric vehicles. As electric vehicles may need to work in complex road conditions and different environment conditions and even some electronic devices may need to operate in poor environment conditions, lithium ion batteries as a power supply may need to suit complex conditions. Especially when the electric vehicles or the electronic devices run in a low temperature environment, the batteries may need to have excellent low temperature charging and discharging performance with high output and input power performance etc.

Normally, under low temperature conditions and during charging of the lithium ion battery, the lithium ion may have a low migrating rate and may be difficult to intercalate into the negative electrode whereas relatively easy to de-intercalate from the negative electrode. Therefore, lithium metal may be deposited and may form so called "lithium dendrites". The reduction reaction of the deposited lithium with the electrolyte may take place and form a new solid electrolyte interface film, i.e. a SEI film, covering an original SEI film. Accordingly, the impedance thereof may be increased and the polarization may be enhanced, and therefore the capacity of the battery may be decreased dramatically which may further cause short circuit in the battery, which may result in negative safety accidents.
To avoid the generation of lithium dendrites and maintain the capacity of the battery, it may be of vital importance to solve the migrating problem of the lithium ion at a low temperature. Currently, the two methods are used as follows: internal electrochemical reactions in the battery are used to improve the low temperature performance of the battery; and a heating device is provided outside of the battery to increase the temperature of the battery so that the battery may work at a suitable temperature. For the latter, according to the conventional methods in the art, starting or stopping battery heating is mainly dependant on detecting only the temperature of the battery. Normally, when the temperature is lower than a predetermined temperature, the heating device starts battery heating, and when the temperature reaches another predetermined temperature, the heating device may stop accordingly.

For example, Chinese Patent Application CN201038282Y discloses a lithium ion battery that is suitable for being used in a low temperature environment and comprises: a battery shell, a thermal insulation layer tightly attached on the battery shell, an electric core disposed in the battery shell, a heating assembly disposed between the electric core and the thermal insulation layer, and a control circuit coupled to the heating device and the electric core respectively. When the internal temperature of the battery is lower than a predetermined temperature, the electric core embedded in a heat conducting cartridge is heated by a controlling assembly composed of a control circuit and a temperature control switch and a heat supplying assembly composed of a heat generating assembly and a heat conducting assembly, and when the temperature of the battery reaches over a predetermined temperature, the control circuit and the temperature control switch to stop the heating assembly.

The conventional temperature controlling method in the art, especially by setting a predetermined constant temperature to stop heating sometimes may not be adapted to all kinds of conditions. As the temperature of the battery is transferred from an internal current collector to other parts, the temperature may not be stable in a short time and a temperature hysteresis thereof may occur. Using the single condition of temperature to determine when to stop heating may not be practical or may not protect the battery effectively.

SUMMARY

In viewing thereof, the present invention is directed to solve at least one of the deficiencies in the art, and to provide a method of heating a battery and a device for heating a battery which may protect the battery more effectively.

According to an aspect of the present invention, a method for controlling battery heating may be provided comprising the following steps of: starting battery heating when conditions for
starting battery heating are met; and stopping battery heating when conditions for stopping battery heating are met. The conditions for stopping battery heating are at least one of the following: (a) an absorbed energy $Q$ of the battery reaching a predetermined energy $\varepsilon_{SET}$; (b) a period of time $T_1$ during which a discharging current $I_x$ of the battery maintains constant, reaching a predetermined period of time $r_{SET}$; (c) the discharging current $I_x$ thereof starting to decrease; and (d) a heating time $T$ reaching a predetermined maximum heating time $r_{max}$.

According to an embodiment of the present invention, a method for controlling battery heating may be provided. The method thereof may comprise the following steps of: starting battery heating when conditions for starting battery heating are met; and stopping battery heating when conditions for stopping battery heating are met. The conditions for stopping battery heating are at least one of the following: (a) a SOC of the battery being not lower than a predetermined SOC $SET$, and a discharging current $I_x$ of the battery reaching a rated current $I_x$ or a heating time $T$ reaching a first maximum heating time $T_{i.max}$, and (b) a SOC of the battery being lower than a predetermined SOC $SET$, and a period of time $T_1$ during which a discharging current $I_x$ of the battery maintains constant reaching a predetermined period of time $T_{SET}$, or the discharging current $I_x$ starting to decrease, or a heating time $T$ reaching a second maximum heating time $r_{max}^2$.

According to an embodiment of the present invention, a device for controlling battery heating, comprising: a battery heating unit for heating the battery; and a control unit connected with a control terminal of the heating unit which is configured to start the heating unit to heat the battery when conditions for starting battery heating are met and to stop the heating unit from heating the battery when conditions for stopping battery heating are met. The conditions for stopping battery heating may be at least one of the following: (a) an absorbed energy $Q$ of the battery reaching a predetermined energy $\varepsilon_{SET}$; (b) a period of time $T_1$ during which a discharging current $I_x$ of the battery maintains constant reaching a predetermined period of time $T_{SET}$; (c) the discharging current $I_x$ starting to decrease; and (d) a heating time $T$ reaching a predetermined maximum heating time $T_{max}^1$.

According to an embodiment of the present invention, a device for controlling battery heating may be provided. The device thereof may comprise: a heating unit for heating the battery; and a control unit connected with a control terminal of the heating unit and configured to start the heating unit to heat the battery when conditions for starting battery heating are met and to stop the heating unit from heating the battery when conditions for stopping battery heating are met. The conditions for stopping battery heating may be at least one of: (a) a SOC of the battery being not lower than a predetermined SOC $SET$, and the discharging current $I_x$ of the battery reaching a rated current $I_x$ or the heating time $T$ reaching a first maximum heating time $T_{i.max}$; and (b) a SOC of the
battery being lower than a predetermined $\text{SOC}_{\text{SET}}$, and a period of time $T_1$ during which a discharging current $I$ of the battery maintains constant reaching a predetermined period of time $T_{\text{SET}}$, or the discharging current $I$ starting to decrease, or the heating time $T$ reaching a second maximum heating time $r_{2\text{max}}$.

Comparing with controlling of battery heating based solely on a single condition of temperature in the art, the method and the device according to the present invention take a plurality of factors including temperature, discharging current, battery SOC, heating time, etc. into considerations to determine when to stop battery heating, which may meet the requirements of the practical applicabilities and not damage the battery but prolong the battery lifespan. Especially in the case of SOC, the conditions for stopping battery heating may include the discharging current and the heating time etc for the high and low SOC respectively which may be more adapted to the requirements under different SOC. Thus, the battery in a low temperature environment may be effectively heated to ensure the battery charging/discharging performance under an optimal working temperature. Further, the battery may not be damaged accidentally, and operating efficiency and lifespan of the battery may be enhanced greatly.

**BRIEF DESCRIPTION OF THE DRAWINGS**

These and other aspects and advantages of the invention will become apparent and more readily appreciated from the following descriptions taken in conjunction with the drawings in which:

- Fig. 1 shows a flow chart for controlling battery heating according to an embodiment of the present invention;
- Fig. 2 shows a flow chart for controlling battery heating according to a preferred embodiment of the present invention;
- Fig. 3 shows a schematic diagram of the device for controlling the heating of the battery according to an embodiment of the present invention;
- Fig. 4 shows a schematic diagram of the device for controlling the heating of the battery according to a preferred embodiment of the present invention;
- Fig. 5 shows a flow chart for controlling the heating of the battery according to another embodiment of the present invention;
- Fig. 6 shows a flow chart for controlling the heating of the battery according to another preferred embodiment of the present invention; and
- Fig. 7 shows a schematic diagram of the device for controlling battery heating according to another preferred embodiment of the present invention.
DETAILED DESCRIPTION OF THE EMBODIMENTS

Reference will be made in detail to embodiments of the present invention. The embodiments described herein with reference to drawings are explanatory, illustrative, and used to generally understand the present invention. The embodiments shall not be construed to limit the present invention. The same or similar elements and the elements having same or similar functions are denoted by like reference numerals throughout the descriptions.

Firstly, the term "battery" in the present invention may be understood to refer to a single cell as well as battery packs comprising a plurality of single cells. The description for "battery" may be applicable to the single cells and the battery packs respectively. For example, for a single cell, the term "positive electrode and negative electrode" may mean the positive electrode and the negative electrode of the single cell, and for a battery pack, the term "positive electrode and negative electrode" may refer to the positive electrode and the negative electrode of the battery pack.

Referring to Fig. 1, the method thereof may comprise two steps of: starting battery heating when meeting the conditions for starting to heat; and stopping battery heating when the conditions for stopping battery heating may be met. The conditions for stopping battery heating may be at least one of:

(a) an absorbed energy $Q$ of the battery reaching a predetermined energy $\varepsilon_{SET}$;
(b) a period of time $T_j$ during which a discharging current $I_e$ of the battery maintains constant reaching a predetermined period of time $T_{SET}$;
(c) the discharging current $I_e$ starting to decrease; and
(d) a heating time $T$ reaching a predetermined maximum heating time $T_{max}$.

As long as at least one of the above conditions is met, the battery heating may be stopped.

As shown in Fig 5, the controlling method according to another embodiment of the present invention may comprise two steps of: starting battery heating when conditions for starting battery heating may be met; and stopping battery heating when conditions for stopping battery heating may be met. The conditions for stopping battery heating may be at least one of: (a) a SOC of the battery being not lower than a predetermined SOC $SOC_{SET}$, and the discharging current $I_e$ of the battery reaching a rated current $I_r$ or the heating time $T$ reaching a first maximum heating time $T_{1max}$; and
(b) a SOC of the battery being lower than a predetermined SOC $SOC_{SET}$, and a period of time $T_j$ during which a discharging current $I_e$ of the battery maintains constant reaching a predetermined period of time $T_{SET}$, or the discharging current $I_e$ starting to decrease, or the heating time $T$ reaching a second maximum heating time $T_{2max}$.

As long as at least one of the above conditions is met, the heating of the battery may be
stopped accordingly.

The parameters in the above mentioned conditions for stopping battery heating will be described in detail as follows.

The State of Charge (SOC) of the battery means the percentage of the remaining actual electricity quantity in the electricity quantity of the fully charged battery. According to an embodiment of the present invention, it may be calculated according to an open circuit voltage (OCV).

The SOC\textsubscript{SET} may be preset according to practical requirements and may be used to distinguish a high SOC from a low SOC. According to an embodiment of the present invention, the range of the SOC may be about 50%-90%, more preferably, about 60%. That is to say, when SOC $\geq 60\%$, the battery is in the high SOC. And when SOC $< 60\%$, the battery is in the low SOC.

The rated current $I_{x}$ may be determined based on different nominal capacities of the battery. For example, for a battery having a nominal capacity of 50 Ah, $I_{x}$ may be about 2600 A; and for a battery having a nominal capacity of about 200 Ah, $I_{x}$ may be about 8000 A.

$r_{i_{\text{max}}}$ may be dependent on the longest bearable heating time under the high SOC condition, and it may be about 30-120 s.

$T_{2_{\text{max}}} \text{ }$ may be dependent on the longest bearable heating time under the low SOC condition, and it may be about 30-360 s.

The heating time $T$ may be obtained in actual operation and may be recorded from the time when starting to heat. Of course, the duration for the heating may be directly set to be not exceeding the first heating time $T_{1_{\text{max}}}$ or the second heating time $r_{2_{\text{max}}}$, so that the heating time $T$ may not need to be recorded.

The absorbed energy $Q$ may be the energy that the battery has absorbed during heating, the unit of which is J. $Q$ may be calculated via a plurality of means.

The predetermined energy $\varepsilon_{\text{SET}}$ may be determined based on the heating temperature $K$ of the battery. According to an embodiment of the invention, $\varepsilon_{\text{SET}}$ may be calculated by the following equation:

$$Q_{\text{SET}} = cm (K_{\text{STOP}} - K_{\text{START}})$$

where $c$ represents a specific heat of the battery, the unit of which is J/(kg-$^{\circ}$C). The specific heat may be obtained by the accumulation of the weighted mass fractions of the positive material, the negative material, the electrolyte and other compositions. For example, $\varepsilon = \sum_{i=1}^{n} C_{i} W_{i}$, where $C_{i}$ represents the specific heat of each composition in the battery, and $W_{i}$ represents the mass fraction of each composition. In the equation, $m$ refers to the mass of the battery, the unit of which
is Kg, and it may be obtained by measuring a plurality of batteries of the same type. \( \sigma_{\text{START}} \) represents the temperature for starting to heat, the unit of which is °C. \( \sigma_{\text{START}} \) is about -50 °C to 0 °C. \( \sigma_{\text{STOP}} \) represents the temperature for stopping battery heating, the unit of which is °C. \( K_{\text{STOP}} \) is about 0 °C to 25 °C. And \( K_{\text{START}} < K_{\text{STOP}} \).

The discharging current / may be obtained in practical usage, and for example, it may be detected by a Hall current sensor.

The predetermined maximum heating time \( r_{\text{max}} \) may be determined based on the maximum bearable time, and may be about 30 s-360 s.

What needs to be explained is that the heating time may be measured in actual operation of the battery, and may be recorded from the time when starting battery heating. Of course, the duration for heating may be directly set to not exceeding the first heating time \( T_{1\text{max}} \) or the second heating time \( T_{2\text{max}} \), so that the heating time \( T \) may not need to be recorded.

The time \( T \) during which the discharging current / maintains constant may be tested in actual operation of the battery. For example, a Hall current sensor may be used to test the discharging current and the current is circularly sampled. The time period \( T \) may be obtained by recording the time period during which the discharging current / is constant.

The predetermined time \( T_{\text{SET}} \) may be preset according to practical requirements, the range of which is about 10-30 s, particularly about 30 s.

Some preferred embodiments will be described below with reference to Fig. 2 and Fig. 6.

Firstly, there are no special limits on the conditions for starting to heat and a variety of suitable conditions for starting to heat may be used additionally or alternatively. For example, as shown in Fig. 2 and Fig. 6, when the temperature \( K \) of the battery is lower than a predetermined temperature \( \sigma_{\text{START}} \), the heating of the battery may be started.

In this case, the battery temperature \( K \) may need to be detected, and a temperature sensor may be used. For a battery pack comprising a plurality of single cells, a plurality of temperature sensors may be used to detect the temperature of each cell, the lowest temperature of which may be selected as the battery temperature \( K \) detected.

The heating method may be any of the suitable methods in the art. For example, the electric heating device may be used for heating. According to an embodiment of the present invention, short circuit in the battery may be used to cause high current so as to increase the temperature of the battery. Short circuit may be realized by a switch module connected between the positive electrode and the negative electrode of the battery (for example an IGBT module). By turning on the switch module, short circuit of the battery may take place in a very short time.

While using the short circuiting, the energy \( Q \) which the battery has absorbed may be
obtained by calculating a released energy $Q_D$ during discharging upon the short circuit which may be calculated by the following equation:

$$Q_D = I^2 R t$$

in which $I$ represents the discharging current of the battery, the unit of which is A. $t$ represents the discharging time, the unit of which is s (second). $R$ represents the internal resistance of the battery, which may vary depending on different temperature $K$ according to the equation $R = a + be^{-cK}$, in which $a$, $b$, $c$ represent the parameters detected for a specific type of battery. The testing method may comprise the steps of: keeping batteries of the same type at a certain temperature (-40°C to 40°C) for at least about 4 hours to let the temperature of the battery be stable, and then using a current with a frequency of 1 KHz to test the alternating current (AC) internal resistance, so that the internal resistance at different temperatures may be tested to fit the equation $R = a + be^{-cK}$, in which $a$ may be about 0.1-0.5, $b$ may be about 0.01 to 0.1, and $c$ may be about 0.05 to 0.1. For example, after testing a certain type of battery, the results may be obtained as follows: $a=0.5$, $b=0.1$ and $c=0.1$.

The internal resistance equation may be substituted into the calculation equation of $Qu$, and after performing quadratic integration to $t$, $K$, the following equation may be obtained:

$$Q_D = \int J I^2 (a + be^{-cK}) t dt dK$$

Periodically performing integration to $Q_D$ the sampling periodicity may be 0.1 s, 0.2 s, 0.5 s or 1 s. When $Q_D$ reaches the predetermined $\varepsilon_{SET}$, the conditions for stopping battery heating may be satisfied.

To avoid unnecessary damage to the battery due to the long-time short circuiting, the time for turning on and turning off the switch module may need to be controlled. The turning on and turning off of the switch module may be triggered by a pulse sequence. Particularly, the pulse width may be about 1-3 ms, more particularly 1-2 ms. The duty ratio may be about 5-30%, particularly 5-10%. The duration may range from about 30 s to the predetermined maximum heating time $r_{max}$ which may be particularly about 60-360 s.

When starting to heat, the heating time $T$ may be recorded from the beginning, so as to compare with the predetermined maximum heating time $T_{max}$. By setting the heating time to be not greater than the predetermined maximum heating time $r_{max}$, the above step may be omitted.

According to an embodiment of the present invention, during heating the battery, the absorbed energy $Q$, the discharging current $I$ and the heating time $T$ (not necessary) of the battery may be detected. Whether to satisfy the conditions for stopping battery heating may be decided according to the detailed flow chart shown in Fig 2, and once at least one of the conditions is met, the heating of the battery may be stopped to avoid the damage to the performance and the lifespan.
of the battery. Of course, the flow chart shown in Fig. 2 is not exclusive. Those skilled in the art may design other flows according to the conditions listed in the present invention.

According to another embodiment of the present invention, during heating of the battery, the battery SOC, the discharging current and the heating time T (not necessary) of the battery may be detected. Whether to satisfy the conditions for stopping battery heating may be decided according to the detailed flow chart shown in Fig. 6, and once at least one of the conditions is met, the heating of the battery may be stopped to avoid the damage to the performance and the lifespan of the battery. Of course, the flow chart shown in Fig 6 is not exclusive. Those skilled in the art may design other flows according to the conditions listed in the present invention.

The device for controlling the heating of the battery is further described in conjunction with Fig. 3, Fig. 4 and Fig. 7.

As shown in Fig. 3, according to an embodiment of the present invention, the device 10 for controlling the heating of the battery may comprise: a battery heating unit 1 for heating the battery; and a control unit 2 connected with a control terminal of the heating unit 1 and configured to start the heating unit 1 to heat the battery when meeting the conditions for starting to heat and to stop the heating unit 1 from heating the battery when meeting the conditions for stopping battery heating. The conditions for stopping battery heating may be at least one of: (a) an absorbed energy Q of the battery reaching a predetermined energy $\varepsilon_{SET}$; (b) a period of time $T_f$ during which a discharging current $I$ of the battery maintains constant reaching a predetermined period of time $T_{SET}$; (c) the discharging current $I$ starting to decrease; and (d) a heating time $T$ reaching a predetermined maximum heating time $T_{max}$.

According to another embodiment of the present invention, the conditions for stopping battery heating may be at least one of: (a) a SOC of the battery being not lower than a predetermined SOC $\varepsilon_{SET}$, and the discharging current $I$ of the battery reaching a rated current $I_r$ or the heating time $T$ reaching a first maximum heating time $T_{max}$; and (b) a SOC of the battery being lower than a predetermined SOC $\varepsilon_{SET}$, and a period of time $T_f$ during which a discharging current $I$ of the battery maintains constant reaching a predetermined period of time $T_{SET}$, or the discharging current $I$ starting to decrease, or the heating time $T$ reaching a second maximum heating time $T_{max}$.

The battery heating unit 1 may be any heating device for the battery, for example, a conventional electric heating device (e.g. an electric heating wire) may be used. However, this kind of device may be generally more complex and may occupy a larger space, so that the volume of the battery assembly may become greater. Therefore, the electric device or equipment may need a larger space for accommodating the battery.
To solve the above mentioned problem, the heating unit 1 according to an embodiment of the present invention may comprise a switch module connected between the positive electrode and the negative electrode. When turning on the switch module, short circuiting of the battery may take place. Actually, the switch module itself may not have a heating function for the battery, but by turning on the switch module, an internal short circuit of the battery may occur instantaneously and cause a high immediate current, thus increasing the temperature of the battery due to the heat thus generated. Comparing with conventional electric heating device, the switch module may have a simpler structure and a smaller volume and may be adapted to the electric device or equipment with a limited space.

The switch module may be any switch circuit, for example a triode, a MOS transistor and so on, providing that they may cause short circuit in the manner of a pulse and may not damage the battery and affect the battery performance.

According to a particular embodiment, the switch module may be an insulated gate bipolar transistor (IGBT) module having a drain, a source and a grid. The drain (i.e. the control terminal) may be configured to be connected with a control unit 2, the source may be configured to be connected with the positive electrode or the negative electrode, and the drain may be configured to be connected with the remaining one of the negative electrode and the positive electrode (depending on the P or N type of the IGBT). The IGBT module has the advantages of both the power field effect transistor and the electronic transistor and may have a plurality of advantages such as high input impedance, fast working speed, excellent heat stability, simple driving circuit, low on-state voltage, high voltage durability and high current durability. Particularly, the switch module may comprise a plurality of IGBT modules connected in parallel, one of which may be turned on to cause the short circuiting.

Suitable IGBT modules having proper withstanding voltage or withstanding current may be selected by those skilled in the art according to different types or designed capacities of batteries. Particularly, the IGBT having a voltage duration value of above 1000 V may be selected, and more particularly a voltage duration value of above 1200 V may be selected. According to another particular embodiment, when the designed capacity is below 100 Ah, IGBT with a current duration value of 3000-5000 A may be used; and when the designed capacity of the battery is above 100 Ah, the IGBT with a current duration value of about 5000-10000 A may be used.

As shown in Fig. 3, a control unit 2 may control the heating of the battery heating unit 1, and the controller being able to send control signals, for example Single Chip Microcomputer (SCM), DSP and so on, may be selected as the control unit 2 depending on the battery heating unit 1.

According to an embodiment of the present invention, in the case of a heating method using
a switch module, the control unit 2 may be particularly a pulse generator which is able to generate
a pulse sequence and is output to the control terminal of the switch module to turn on or turn off
the switch module. To avoid unnecessary damages to the battery by the long time short circuit, the
time for turning on and turning off the switch module may need to be controlled. The turning on
and turning off of the switch module may be triggered by the pulse sequence. According to an
embodiment of the invention, the pulse width may be about 1-3 ms, more particularly 1-2 ms. The
duty ratio may be about 5-30%, particularly 5-10%. The duration may range from about 30 s to
the predetermined maximum heating time \( t_{\text{max}} \) which may be particularly about 60-360 s.

When generating a control signal, the control unit 2 may need to determine whether the
conditions for starting or stopping the heating of the battery are met.

There are no special limits on the conditions for starting to heat, and a variety of suitable
conditions for starting battery heating may be used. For example, when the temperature \( K \) of the
battery is lower than a predetermined temperature \( T_{\text{START}} \), the heating of the battery may be started,
where \( S_{\text{START}} < S_{\text{STOP}} \), and \( S_{\text{START}} \) may range from about -50°C to about 0°C.

In this case, the battery temperature \( K \) may need to be detected. According to an embodiment
of the present invention, as shown in Fig. 4 and Fig. 7, the device 10 for controlling the heating of
the battery may further comprise a temperature detecting unit 3 connected with the control unit 2
and may be configured to detect the battery temperature \( K \) and then output thereof to the control
unit 2. At this time, the received temperature \( K \) may be compared with the temperature \( S_{\text{START}} \) for
starting battery heating by the control unit 2 and whether to start battery heating may be
determined according to the comparison result. The temperature detecting unit 3 may be any
temperature sensing device. According to an embodiment of the invention, a temperature sensor
may be used. And according to another embodiment of the invention, the number of the sensors
may be the same as that of the single cells. When the control unit 2 receives a plurality of
temperatures, the lowest one of these may be selected as the battery temperature \( K \).

The present invention is mainly directed to improve the conditions for stopping battery
heating. When the control unit 2 determines the conditions for stopping battery heating, the
energy absorbed \( Q \), the SOC, the discharging current \( i \) and the heating time \( T \) (not necessary) of
the battery may be required. Therefore, according to some embodiments of the invention, the
device 10 for controlling battery heating may further comprise some units or devices for obtaining
the above information.

According to an embodiment of the present invention, the following processes may be
performed by the control unit 2.

Firstly, the control unit 2 may need to decide when the absorbed energy \( Q \) reaches the
predetermined energy $\varepsilon_{SET}$. In this case, the device 10 may further comprise an energy calculation unit 6 connected with the control unit 2 for calculating the absorbed energy $Q$ of the battery and then outputting the energy $Q$ to the control unit 2. The calculating method of the energy $Q$ may be the same as that described in the above method and thus will be omitted herein for clarity. When it is found by the control unit 2 that the absorbed energy $Q$ reaches the predetermined energy $\varepsilon_{SET}$, a control signal for stopping battery heating may be output immediately by the control unit 2.

Secondly, the control unit 2 may further need to detect the discharging current $I$. As shown in Fig. 4, the device 10 may further comprise a current detecting unit 4 connected with the control unit 2 for detecting the discharging current $I$ of the battery and then outputting the obtained discharging current $I$ to the control unit 2. The control unit 2 may decide whether the detected discharging current $I$ is changing, and if not, the control unit 2 starts to record the time period $T_I$ during which the discharging current $I$ maintains constant. If $T_I$ reaches a predetermined time $T_{SET}$, the control unit 2 may output a control signal for stopping battery heating. If $I$ starts to decrease, the controlling unit 2 may also output a control signal for stopping battery heating. The current detecting unit 4 may be any kind of device that is capable to detect the current. Particularly, a Hall current sensor may be used.

Thirdly, the control unit 2 may further determine to stop battery heating according to the heating time $T$ by two following methods.

One is shown in Fig 4. The device 10 may further comprise a timing unit 5 connected with the control unit 2 for recording the heating time $T$ of the heating unit 1 under the control of the control unit 2, and then outputting a signal to the control unit 2 when $T$ reaches the predetermined maximum heating time $T_{max}$. At this time, the control unit 2 may output a control signal for stopping battery heating instantaneously according to the signal received.

The other one is also shown in Fig 4. The duration of the pulse sequence generated by the control unit 2 is set to be not greater than the predetermined maximum heating time $r_{max}$. When the heating time $T$ reaches the maximum heating time, the battery heating may stop automatically.

According to another embodiment of the present invention, the following processes may be performed by the control unit 2.

Firstly, the control unit 2 needs to determine whether the battery is in a high SOC or a low SOC. In this case, as shown in Fig. 7, the device 10 may further comprise an SOC evaluation unit 6 connected with the control unit 2 for evaluating the SOC of the battery and then outputting the evaluated SOC to the control unit 2. The control unit may determine whether the battery is in a high SOC or low SOC after comparing the received SOC with the SOC $\text{SOC}_{SET}$. The SOC evaluation unit 6 may operate by any SOC evaluation methods, for example, by evaluating the battery SOC
according to the open circuit voltage of the battery.

If the battery is in a high SOC, the control unit 2 may further detect the discharging current / \( I_f \).

As shown in Fig. 4, the device 10 may further comprise a current detecting unit 4 connected with the control unit 2 for detecting the discharging current / \( I_f \) of the battery and then outputting the obtained discharging current / \( I_f \) to the control unit 2. The control unit 2 may compare the discharging current / \( I_f \) with the rated current \( I_f \) and if \( I_f \) reaches \( I_f \), the control unit may output a control signal for stopping battery heating. The current detecting unit 4 may be any device which is capable of detecting the current. Particularly, a Hall current sensor may be used.

If the battery is in a low SOC, the control unit may further detect the discharging current / by the current detecting unit 4. The control unit 2 may decide whether the detected discharging current / \( I_f \) is changing. If not, the control unit 2 may then start to record the time period \( T_f \) during which the discharging current / \( I_f \) maintains constant. If \( T_f \) reaches a predetermined time \( T_{SET} \), the control unit 2 may output a control signal for stopping battery heating. If the discharging current / \( I_f \) starts to decrease, the controlling unit 2 may also output a control signal for stopping battery heating.

Besides, the control unit 2 may further decide whether to stop battery heating according to the heating time by two following methods.

Firstly, as shown in Fig. 4, the device 10 may further comprise a timing unit 5 connected with the control unit 2 for calculating the heating time \( T \) of the heating unit 1 controlled by the control unit 2, and then outputting a signal to the control unit 2 when \( T \) reaches the first maximum heating time \( T_{1max} \) or the second maximum heating time \( T_{2max} \). The control unit 2 may output a control signal for stopping battery heating according to the received signal.

Secondly, the control unit 2 may directly set a duration for the pulse sequence after comparing the battery SOC with the SOC \( \text{SET} \). For a high SOC (SOC \( \geq \) SOC \( \text{SET} \)), the duration may not exceed the first maximum heating time \( T_{1max} \), and for a low SOC (SOC \( < \) SOC \( \text{SET} \)), the duration may not exceed the second maximum heating time \( T_{2max} \). When the heating time \( T \) reaches the first heating time or the second heating time, the heating of the battery may stop automatically.

Although explanatory embodiments have been shown and described, it would be appreciated by those skilled in the art that changes, alternatives, and modifications all falling into the scope of the claims and their equivalents may be made in the embodiments without departing from spirit and principles of the invention.
WHAT I CLAIMED IS:

1. A method for controlling battery heating comprising the steps of:
   starting battery heating when conditions for starting battery heating are met; and
   stopping battery heating when conditions for stopping battery heating are met; wherein the conditions for stopping battery heating are at least one of the following:
   (a) an absorbed energy \( Q \) of the battery reaching a predetermined energy \( \varepsilon_{\text{SET}} \);
   (b) a period of time \( T_i \), during which a discharging current \( i \) of the battery maintains constant, reaching a predetermined period of time \( T_{\text{SET}} \);
   (c) the discharging current \( i \) thereof starting to decrease; and
   (d) a heating time \( T \) reaching a predetermined maximum heating time \( T_{\text{max}} \).

2. The method according to claim 1, wherein the predetermined period of time \( T_{\text{SET}} \) is about 10 s-30 s, and the predetermined maximum heating time \( T_{\text{max}} \) is about 30 s to 360 s.

3. The method according to claim 1, wherein the predetermined energy \( \varepsilon_{\text{SET}} \) is calculated by setting a battery heating temperature \( K \).

4. The method according to claim 1, wherein the predetermined energy \( \varepsilon_{\text{SET}} \) is calculated by the following equation:

\[
Q_{\text{SET}} = c m (K_{\text{STOP}} - K_{\text{START}})
\]

where \( c \) represents the specific heat with a unit of J/(kg - °C);

\( m \) represents the mass of the battery with a unit of Kg;

\( K_{\text{START}} \) represents the temperature for starting battery heating with a unit of °C ranging from about -50 °C to 0 °C; and

\( K_{\text{STOP}} \) represents the temperature for stopping battery heating with a unit of °C ranging from about 0 °C to 25 °C; wherein \( K_{\text{START}} < K_{\text{STOP}} \).

5. The method according to any of claims 2-4, wherein the battery heating is implemented by turning on a switch module connected between a positive electrode and a negative electrode to cause short circuiting of the battery to increase the temperature thereof.

6. The method according to claim 1, wherein the battery heating is implemented by turning on a switch module connected between a positive electrode and a negative electrode to cause short circuiting of the battery to increase the temperature thereof.

7. The controlling method according to claim 6, wherein the absorbed energy \( Q \) which the battery has absorbed is obtained by calculating a released energy \( Q_0 \) during battery discharging upon short circuiting.

8. The controlling method according to claim 6, wherein the turning on and turning off of the switch module is triggered by a pulse sequence with a pulse width of about 1-3 ms, a duty ratio of
about 5-30%, and a duration ranging from about 30 s to the predetermined maximum heating time $T_{\text{max}}$.

9. The method according claim 1, wherein the conditions for stopping battery heating further comprises at least one of the following:

(a) a SOC of the battery being not lower than a predetermined SOC$_{\text{SET}}$, and the discharging current / of the battery reaching a rated current $I_p$ or the heating time $T$ reaching a first maximum heating time $T_{1\text{max}}$; and

(b) a SOC of the battery being lower than a predetermined SOC$_{\text{SET}}$, and a period of time $T_f$ during which a discharging current / of the battery maintains constant reaching a predetermined period of time $T_{\text{SET}}$, or the discharging current / starting to decrease, or the heating time $T$ reaching a second maximum heating time $T_{2\text{max}}$.

10. The method according to claim 9, wherein the SOC$_{\text{SET}}$ is about 50% to 90%, the $T_{\text{SET}}$ is about 10 s to 30 s, the first maximum heating time $T_{1\text{max}}$ is about 30-120 s, and the second maximum heating time $T_{2\text{max}}$ is about 30-360 s.

11. A method for heating a battery comprising the steps of:

- starting battery heating when conditions for starting battery heating are met; and
- stopping battery heating when conditions for stopping battery heating are met; wherein the conditions for stopping battery heating are at least one of the following:

(a) a SOC of the battery being not lower than a predetermined SOC$_{\text{SET}}$, and a discharging current / of the battery reaching a rated current $I_x$ or a heating time $T$ reaching a first maximum heating time $T_{1\text{max}}$; and

(b) a SOC of the battery being lower than a predetermined SOC$_{\text{SET}}$, and a period of time $T_f$ during which a discharging current / of the battery maintains constant reaching a predetermined period of time $T_{\text{SET}}$, or the discharging current / starting to decrease, or a heating time $T$ reaching a second maximum heating time $T_{2\text{max}}$.

12. The controlling method according to claim 11, wherein the SOC$_{\text{SET}}$ is about 50% to 90%, the $T_{\text{SET}}$ is about 10 s to 30 s, the first maximum heating time $T_{1\text{max}}$ is about 30-120 s, and the second maximum heating time $T_{2\text{max}}$ is about 30-360 s.

13. A device (10) for controlling battery heating, comprising:

- a battery heating unit (1) for heating the battery; and
- a control unit (2) connected with a control terminal of the heating unit (1) which is configured to start the heating unit (1) to heat the battery when conditions for starting battery heating are met and to stop the heating unit (1) from heating the battery when conditions for stopping battery heating are met, wherein
the conditions for stopping battery heating are at least one of the following:

(a) an absorbed energy \( Q \) of the battery reaching a predetermined energy \( \varepsilon_{\text{SET}} \);

(b) a period of time \( T_i \) during which a discharging current \( i \) of the battery maintains constant reaching a predetermined period of time \( T^{\text{SET}}_i \);

(c) the discharging current \( i \) starting to decrease; and

(d) a heating time \( T \) reaching a predetermined maximum heating time \( r_{\text{max}} \).

14. The device according to claim 13, wherein the predetermined period of time \( T_{\text{SET}} \) is about 10 s to 30 s, and the predetermined maximum heating time \( r_{\text{max}} \) is about 30 s to 360 s.

15. The device according to claim 13, wherein the predetermined energy \( Q_{\text{SET}} < \varepsilon_{\text{SET}} \) is calculated by setting a battery heating temperature \( K \).

16. The device according to claim 13, wherein the predetermined energy \( Q_{\text{SET}} < \varepsilon_{\text{SET}} \) is calculated by the following equation:

\[
Q_{\text{SET}} = cm \left( K_{\text{STOP}} - K_{\text{START}} \right)
\]

where \( c \) represents the specific heat with a unit of J/(kg·°C);

\( m \) represents a mass of the battery with a unit of Kg;

\( K_{\text{START}} \) represents the temperature for starting battery heating with a unit of °C ranging from about -50 °C to 0 °C; and

\( K_{\text{STOP}} \) represents the temperature for stopping battery heating with a unit of °C ranging from about 0 °C to 25 °C; wherein \( ^{\text{STOP}} < K_{\text{STOP}} \).

17. The device according to claim 13, wherein the battery heating unit (1) comprises a switching module which is connected between a positive electrode and a negative electrode so that the switching module is conducted to cause short circuiting of the battery to increase the temperature thereof.

18. The device according to claim 17, wherein the absorbed energy \( Q \) which the battery has absorbed is obtained by calculating the released energy \( Q_{\text{DS}} \) during battery discharging upon the short circuiting.

19. The device according to claim 13, further comprising:

an energy calculation unit (6) connected with the control unit (2) for calculating the absorbed energy \( Q \) of the battery and then outputting the absorbed energy \( Q \) to the control unit (2);

a current detecting unit (4) connected with the control unit (2) for detecting the discharging current \( i \) and then outputting the discharging current \( i \) to the control unit (2); and

a timing unit (5) connected with the control unit (2) for calculating the heating time \( T \) of the heating unit (1) under the control of the control unit (2), and then outputting a signal to the control unit (2) when \( T \) reaches the predetermined maximum heating time \( T_{\text{max}} \).
wherein the control unit (2) is configured to:

compare the absorbed energy $Q$ with a predetermined energy $Q_{SET}$ and then output a control signal for stopping battery heating when the absorbed energy $Q$ reaches the predetermined energy $Q_{SET}$;

determine whether the discharging current $I$ is changing according to the detected discharging current $I$, start to record the time $T_i$ when the discharging current $I$ becomes constant, and output a control signal for stopping battery heating when the time $T_i$ reaches a predetermined period of time $T_{SET}$; and

output a control signal for stopping battery heating when the discharging current $I$ starts to decrease.

20. The device according to claim 13, wherein the conditions for stopping battery heating further comprise at least one of the following:

an energy calculation unit (6) connected with the control unit (2) for calculating the absorbed energy $Q$ of the battery and then outputting the $Q$ to the control unit (2); and

a current detecting unit (4) connected with the control unit (2) for detecting the discharging current $I$ and then outputting the discharging current $I$ to the control unit (2);

wherein the control unit (2) determines whether a predetermined pulse sequence duration is not greater than the predetermined maximum heating time $T_{max}$; and

the control unit (2) is further configured to:

compare the absorbed energy $Q$ with the predetermined energy $Q_{SET}$ and then output a control signal for stopping battery heating when the absorbed energy $Q$ reaches the predetermined energy $Q_{SET}$;

determine whether the discharging current $I$ is changing according to the detected discharging current $I$, start to record the time $T_i$ when the discharging current $I$ becomes constant, and output a control signal for stop battery heating when the time $T_i$ reaches a predetermined period of time $T_{SET}$; and

output a control signal for stop battery heating when the discharging current $I$ starts to decrease.

21. The device according to claim 13, wherein the conditions for stopping battery heating further comprise at least one of the following:

(a) a SOC of the battery being not lower than a predetermined $SOC_{SET}$, and the discharging current $I$ of the battery reaching a rated current $I_r$ or the heating time $T$ reaching a first maximum heating time $T_{1max}$; and

(b) a SOC of the battery being lower than a predetermined $SOC_{SET}$, and a period of time $T_i$
during which a discharging current / of the battery maintains constant reaching a predetermined period of time $T_{\text{SET}}$, or the discharging current / starting to decrease, or the heating time $T$ reaching a second maximum heating time $r_{2_{\text{max}}}$.

22. The device according to claim 21, wherein the SOC $\text{SET}$ is about 50% to 90%, the $T_{\text{SET}}$ is about 10 s to 30 s, the first maximum heating time $T_{\text{i max}}$ is about 30-120 s, and the second maximum heating time $r_{2_{\text{max}}}$ is about 30-360 s.

23. The device according to claim 13, further comprising:

an energy calculation unit (6) connected with the control unit (2) for calculating the absorbed energy $Q$ of the battery and then outputting the absorbed energy $Q$ to the control unit (2);

a current detecting unit (4) connected with the control unit (2) for detecting the discharging current / and then outputting the discharging current / to the control unit (2); and

a timing unit (5) connected with the control unit (2) for calculating the heating time $T$ of the heating unit (1) under the control of the control unit (2), and then outputting a signal to the control unit (2) when the heating time $T$ reaches the predetermined maximum heating time $T_{\text{max}}$;

wherein the control unit (2) further compares SOC with SOC $\text{SET}$ to determine whether the battery is in a high SOC which is larger than SOC $\text{SET}$ and a low SOC which is less than SOC $\text{SET}$; and

when the battery is in the high SOC, the control unit (2) further compares the detected discharging current / with $I_\alpha$ and outputs a control signal for stopping battery heating if $I=I_\alpha$ or if the control unit (2) receives a signal from the timing unit (5), the control unit (2) outputs a control signal for stopping battery heating; and

when the battery is in the low SOC, the control unit (2) further determines whether the discharging current / is changing or not, and if not, the control unit (2) then starts to record the period of time $T_i$ during which the discharging current / maintains constant, or if / starts to decrease or the control unit (2) receives a signal from the timing unit (5), the control unit (2) outputs a control signal for stopping battery heating.

24. The device according to claim 13, wherein the device (10) further comprising:

a SOC evaluation unit (6) connected with the control unit (2) for evaluating SOC of the battery and then outputting the evaluated SOC to the control unit (2), and

a current detecting unit (4) connected with the control unit (2) for detecting the discharging current / of the battery and then outputting the obtained discharging current / to the control unit (2);

wherein the control unit (2) further compares SOC with SOC $\text{SET}$ to determine whether the battery is in a high SOC which is larger than SOC $\text{SET}$ and a low SOC which is less than SOC $\text{SET}$.
and

when the battery is in the high SOC, the control unit (2) further compares the detected discharging current / with $I_x$ and outputs a control signal for stopping battery heating if $I=I_k$ or if the control unit (2) receives a signal from the timing unit (5), the control unit (2) outputs a control signal for stopping battery heating; and

when the battery is in the low SOC, the control unit (2) further determines whether the discharging current / is changing, and if not, the control unit (2) then starts to record the period of time $T_1$ during which the discharging current / maintains constant, or if the discharging current / starts to decrease or the control unit (2) receives a signal from the timing unit (5), the control unit (2) outputs a control signal for stopping battery heating.

25. The device according to claim 13, wherein the battery heating unit (1) comprises a switch module configured to connect with the positive electrode and the negative electrode and the temperature of the battery is increased by turning on the switch module to cause short circuiting of the battery.

26. The device according to claim 13, wherein the switch module is an IGBT module having a grid, a source and a drain, the grid is configured to be connected with the control unit (2), the source is configured to be connected with the positive electrode or the negative electrode, and the drain is configured to be connected with the remaining one of the negative electrode and the positive electrode.

27. The device according to claim 13, wherein the control unit (2) is a pulse generator for generating and outputting a pulse sequence to the control terminal of the switch module to turn on or turn off the switch module respectively.
Fig. 1
Fig. 4

Fig. 5
Start
- Detect battery temperature

$K < K_{START}$?
  - yes: Start battery heating
  - no: Evaluate SOC

Evaluate SOC
- $SOC \geq SOC_{SET}$?
  - yes: Detect discharging current $I$
  - no: $T_i = T_{SET}$?

Detect discharging current $I$
- $I = I_1$?
  - yes: $T = T_{1\text{max}}$?
  - no: $T = T_{2\text{max}}$?

- yes: $T_i$ during which $I$ maintains constant
- no: $T_i = T_{SET}$?

Stop battery heating

Fig. 6
Temperature detecting unit 3

Current detecting unit 4

SOC evaluation unit 6

Control unit 2

Battery heating unit 1

Timing unit 5

Fig. 7
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

HOIM 10/50 (2006 01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

P C HOIM

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, CNPAT, CNKI battery/cell, heat+, start+/stop+, energy/temperature, time, discharg÷ current, short circuit, switch+ZIGBT, SOC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No</th>
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<td>CNI 630 129A(BENQ CORP) 22 Jim 2005 (22 06 2005) see claims 14-25, pages 2-5 in the description, and figs 1-2</td>
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Further documents are listed in the continuation of Box C

See patent family annex

* Special categories of cited documents

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim (S) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

& "document member of the same patent family

Date of the actual completion of the international search 28 Jul 2010 (28 07 2010)

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Form PCT/ISA /210 (second sheet) (July 2009)
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