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(54) **BATTERY APPARATUS AND METHOD FOR ESTIMATING BATTERY STATE**

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(57) **ABSTRACT**

A battery apparatus receives a measured current of a battery and estimates a surface SOC representing a potential at an electrode surface of the battery based on a plurality of parameters. The plurality of parameters includes a first parameter determined based on the measured current and a second parameter determined based on an SOC of the battery.

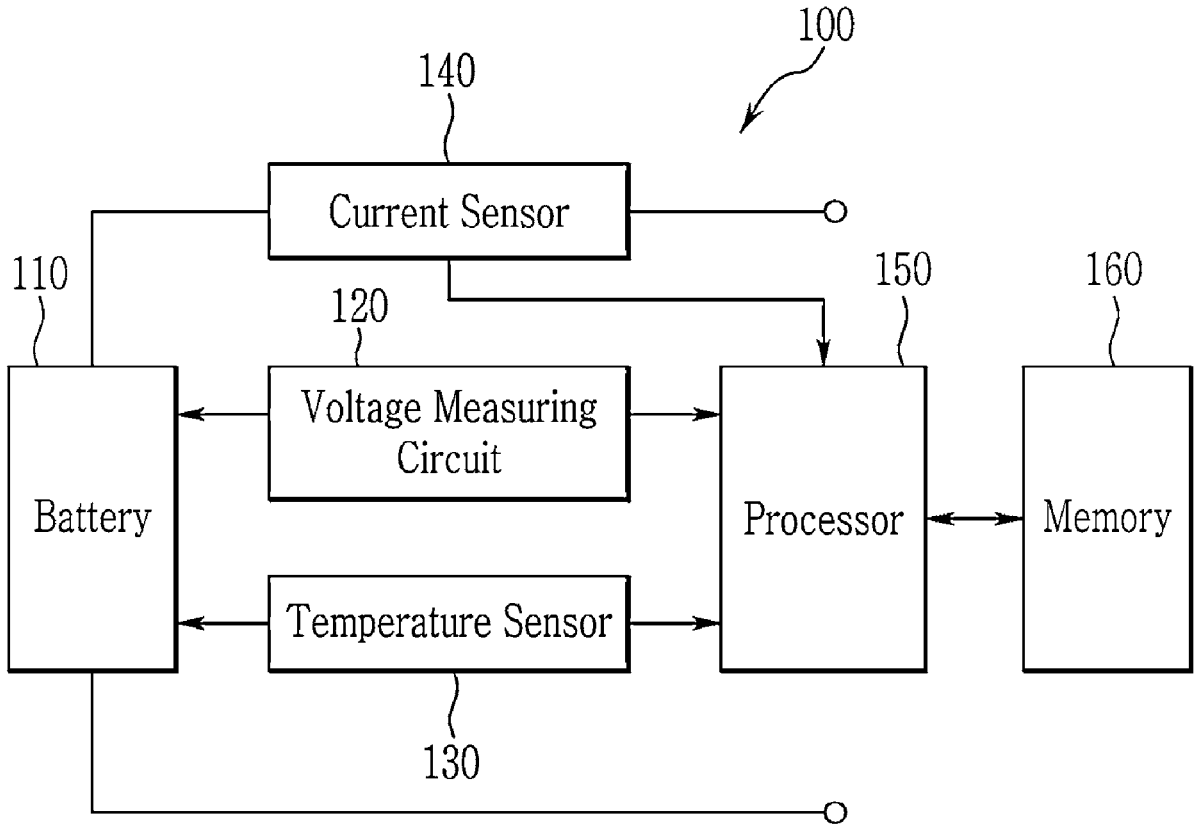


FIG. 1

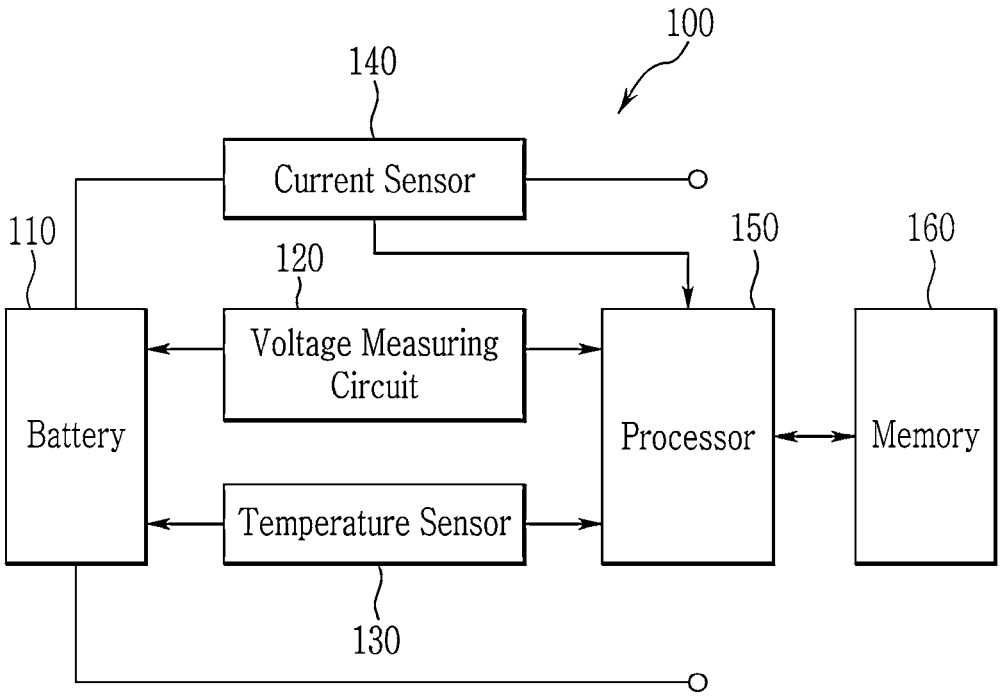

100
140
Current Sensor
110
120
150
160
Voltage Measuring Circuit
Battery
Processor
Memory
Temperature Sensor
130

FIG. 2

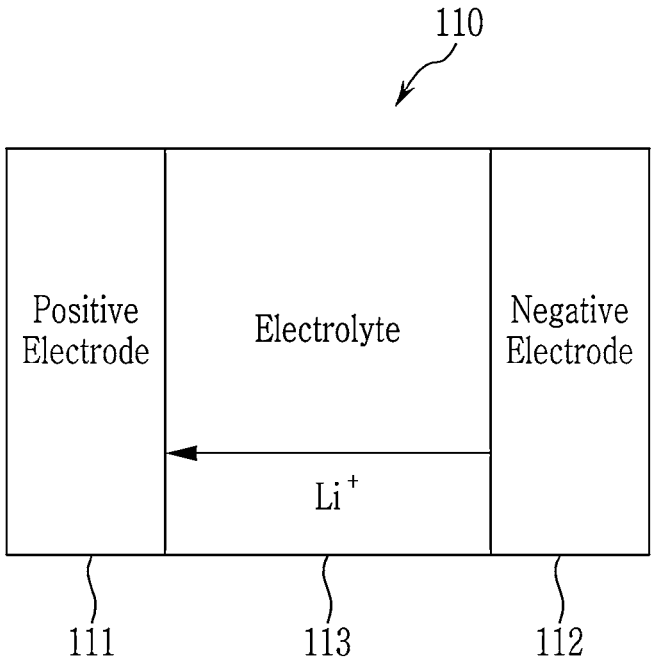

110
Positive Electrode
Electrolyte
Negative Electrode
Li+
111
113
112

FIG. 3

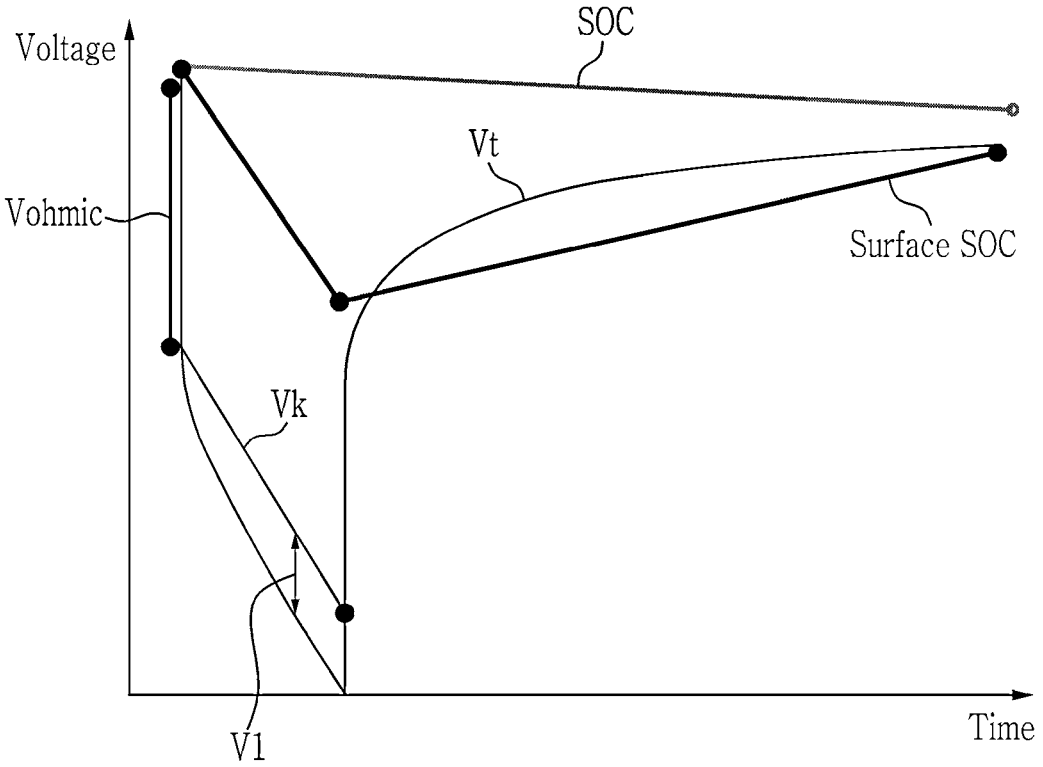


FIG. 4

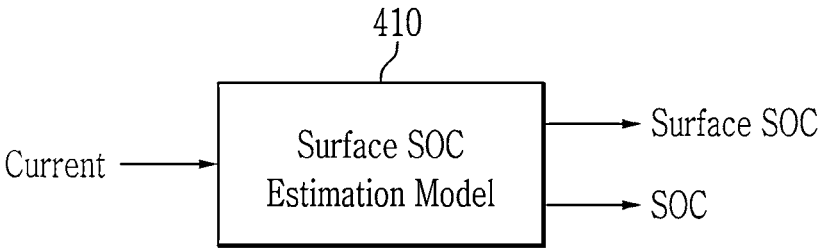


FIG. 5

SOC / Temperature	100%	• • • •	5%
-40℃	K1	• • • •	K2
⋮	⋮	⋱	⋮
60℃	K3	• • • •	K4

FIG. 6

SOC / Temperature	100%	• • • •	5%
-40℃	D1	• • • •	D2
⋮	⋮	⋱	⋮
60℃	D3	• • • •	D4

FIG. 7

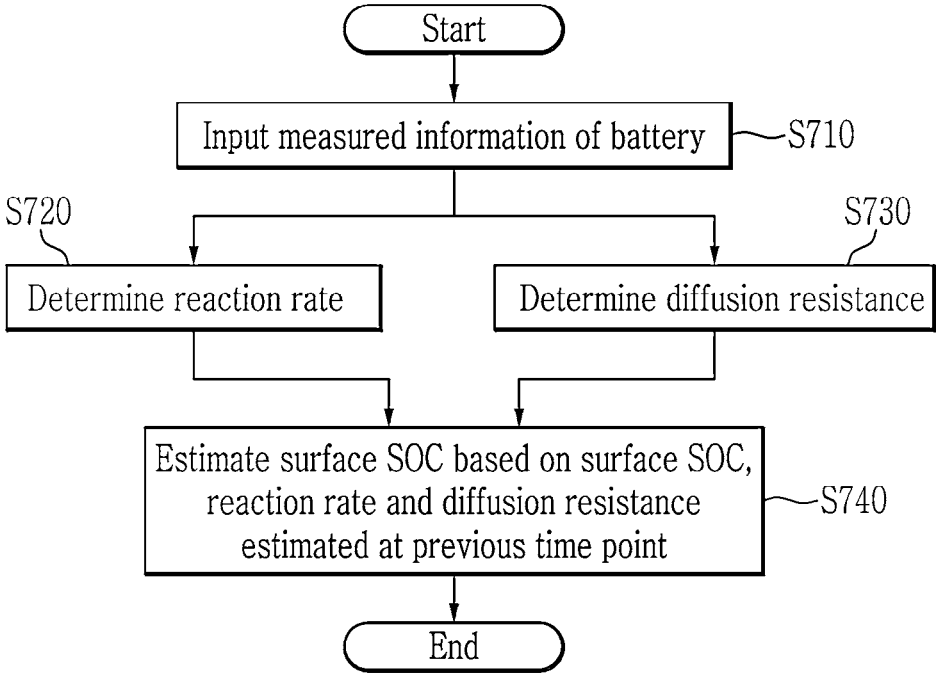

Start
Input measured information of battery
S710
S720
S730
Determine reaction rate
Determine diffusion resistance
Estimate surface SOC based on surface SOC, reaction rate and diffusion resistance estimated at previous time point
S740
End

FIG. 8

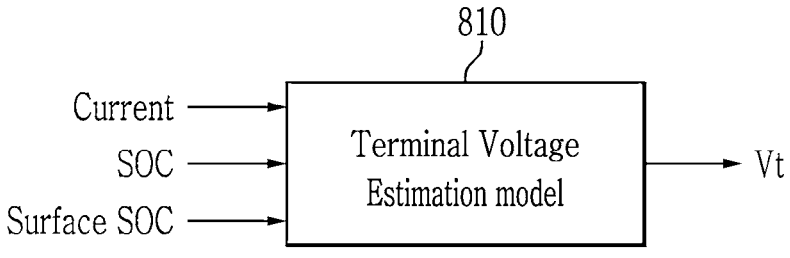

810
Current
SOC
Surface SOC
Terminal Voltage Estimation model
Vt

FIG. 9

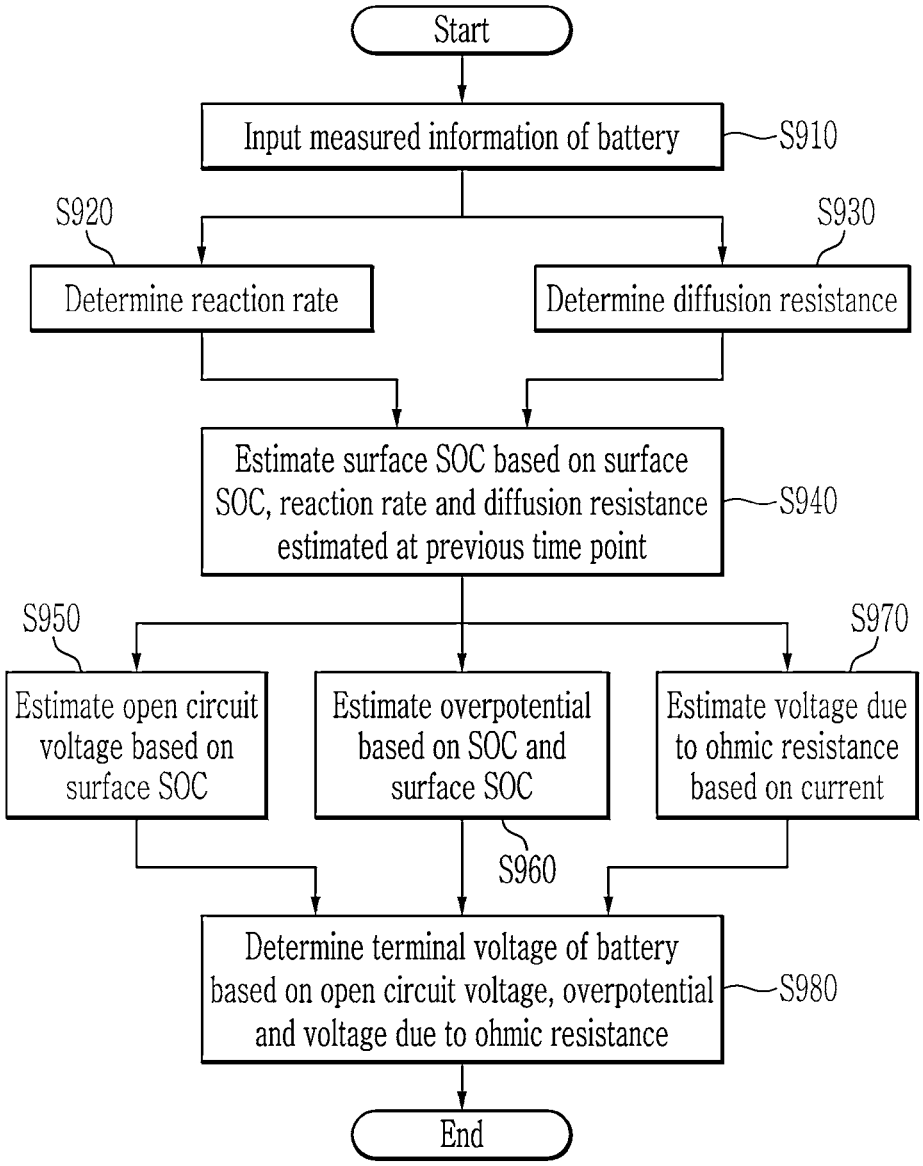

Start
Input measured information of battery
S910
S920
S930
Determine reaction rate
Determine diffusion resistance
Estimate surface SOC based on surface SOC, reaction rate and diffusion resistance estimated at previous time point
S940
S950
S970
Estimate open circuit voltage based on surface SOC
Estimate overpotential based on SOC and surface SOC
Estimate voltage due to ohmic resistance based on current
S960
Determine terminal voltage of battery based on open circuit voltage, overpotential and voltage due to ohmic resistance
S980
End

FIG. 10

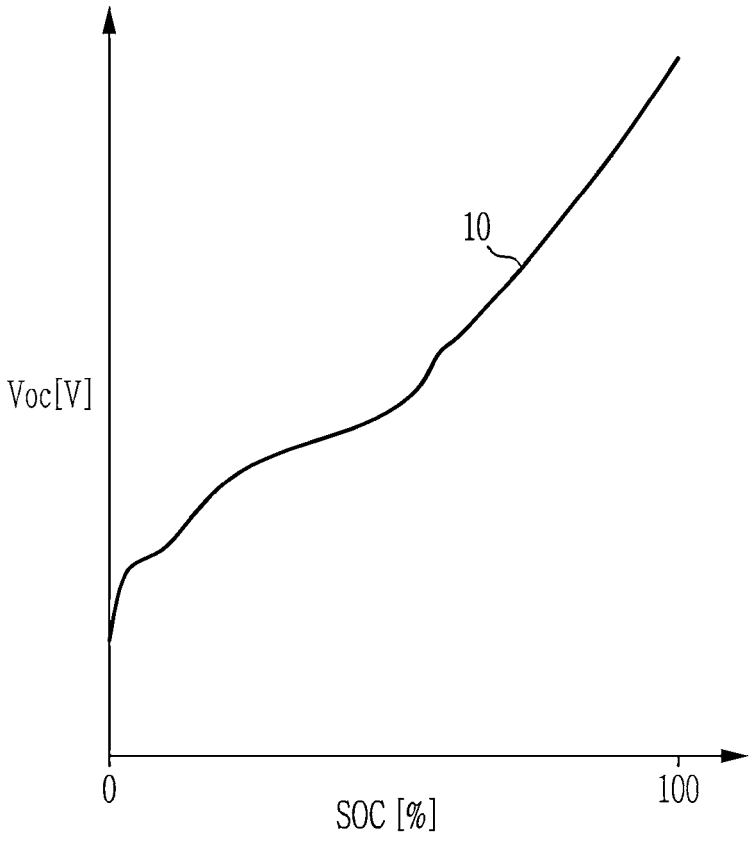


FIG. 11

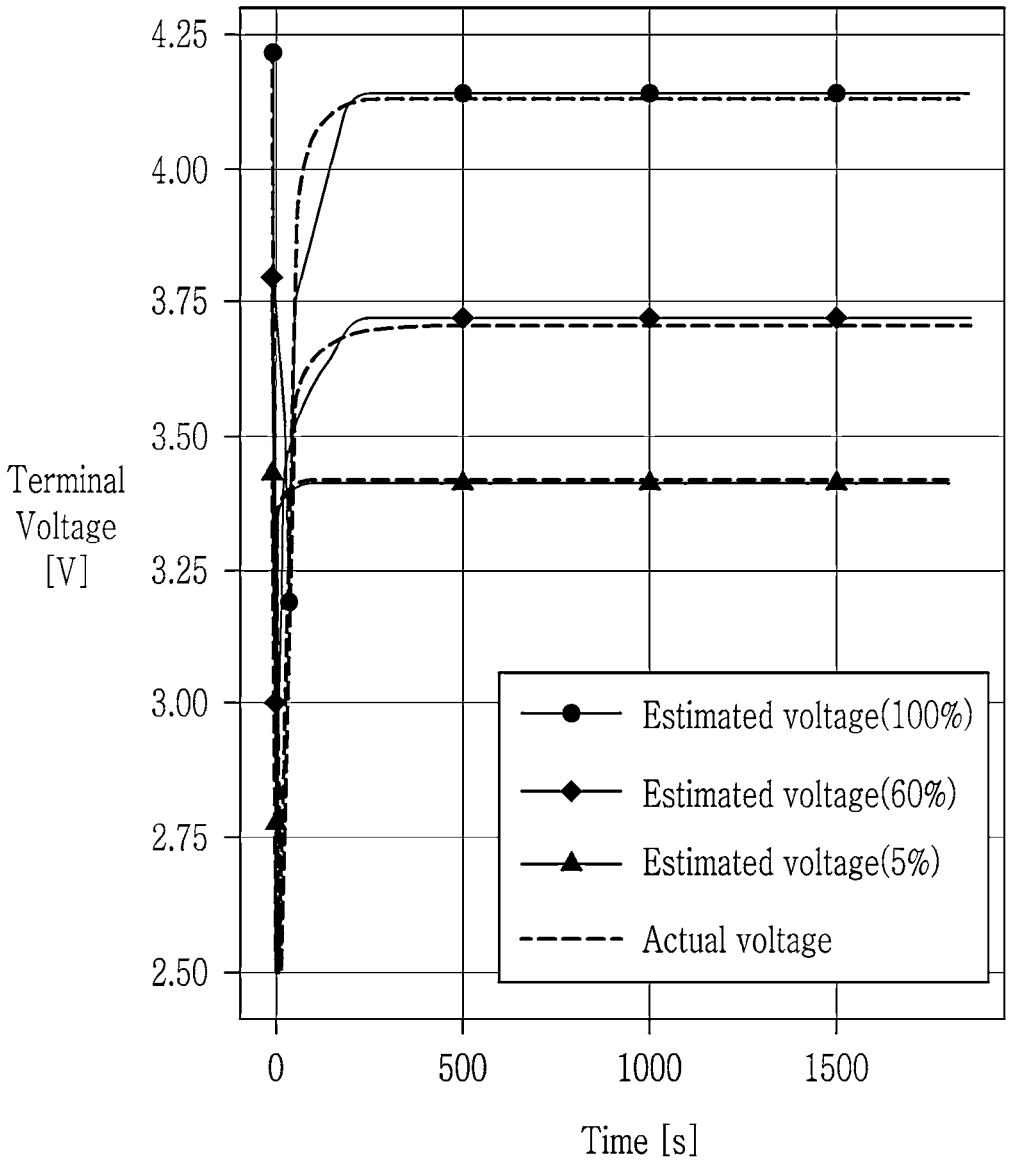
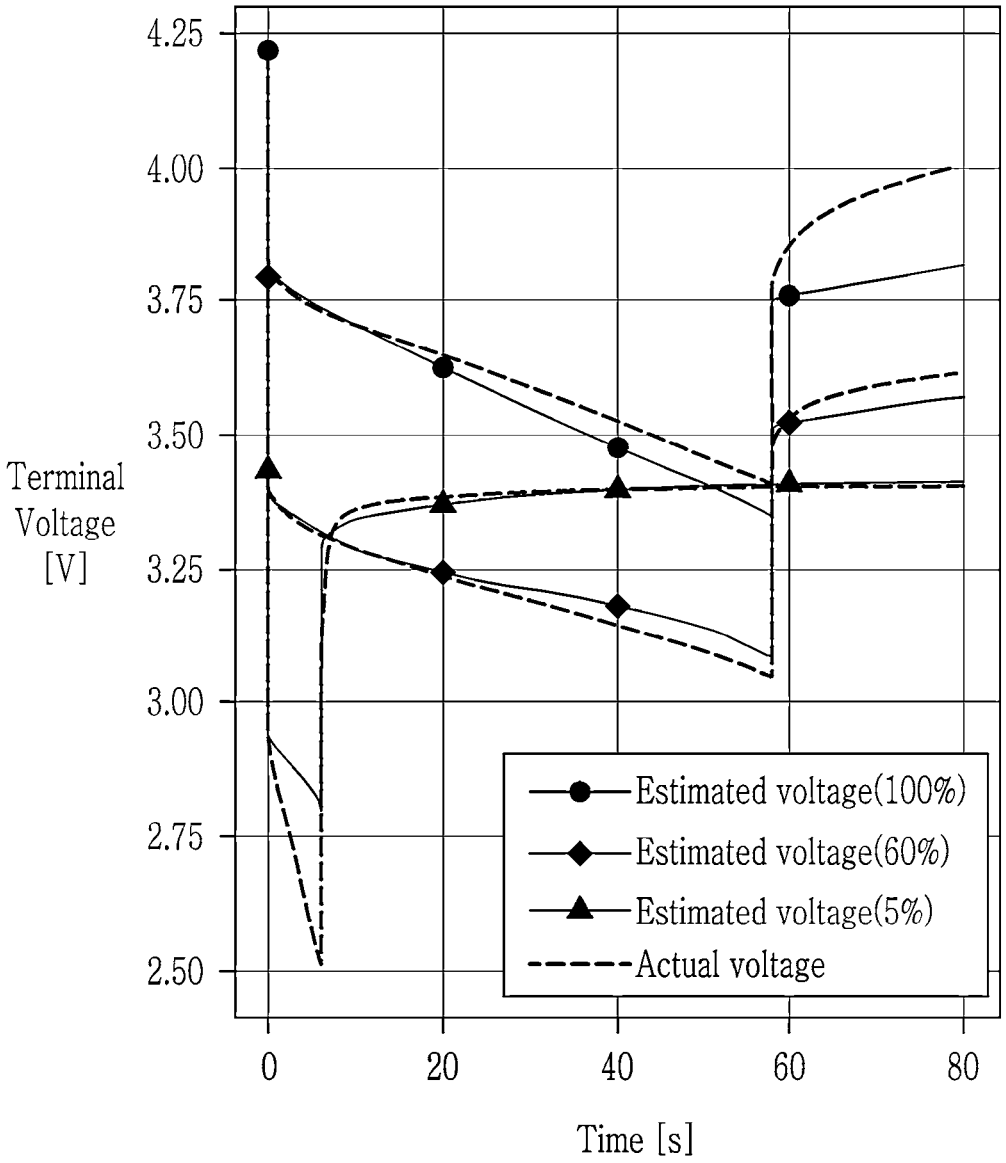

4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
Terminal Voltage [V]
0
500
1000
1500
Time [s]
Estimated voltage(100%)
Estimated voltage(60%)
Estimated voltage(5%)
Actual voltage

FIG. 12


4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
Terminal Voltage [V]
0
20
40
60
80
Time [s]
Estimated voltage(100%)
Estimated voltage(60%)
Estimated voltage(5%)
Actual voltage

BATTERY APPARATUS AND METHOD FOR ESTIMATING BATTERY STATE

TECHNICAL FIELD

Cross-Reference to Related Application

[0001] This application claims priority to and the benefit of Korean Patent Application No. 10-2020-0122153 filed in the Korean Intellectual Property Office on Sep. 22, 2020, the entire contents of which are incorporated herein by reference.

[0002] The described technology relates to a battery apparatus and a method for estimating a battery state.

BACKGROUND ART

[0003] An electric vehicle or a hybrid vehicle is a vehicle that obtains power by driving a motor mainly using a battery as a power source. The electric vehicles are being actively researched because they are alternatives that can solve pollution and energy problems of internal combustion vehicles. Rechargeable batteries are used in various external devices other than the electric vehicles.

[0004] One of important states used when managing a battery is a state of charge (SOC). The SOC is a factor representing a relative ratio of a remaining capacity to a full charge capacity representing a maximum amount of charge that can be stored in the battery. The SOC represents an average concentration of active materials inside the battery.

[0005] An equivalent circuit model using the SOC of the battery is mainly used in order to estimate a terminal voltage of the battery. The SOC in the equivalent circuit model is suitable for estimating a state of a battery in a static state, such as an open circuit. However, in situations where the battery is being used dynamically, such as a situation where the battery is continuously being charged or discharged, or a situation where a vehicle mounted with the battery is running, the current effect cannot be reflected so that an error of state estimation may increase.

DISCLOSURE

Technical Problem

[0006] Some embodiments may provide a battery management system and a method for estimation a battery state, capable of accurately estimating a battery state and a battery state estimation method.

Technical Solution

[0007] According to an embodiment, a battery apparatus including a battery and a processor is provided. The processor receives a measured current of the battery, and estimates a surface SOC representing a potential at an electrode surface of the battery based on a plurality of parameters including a first parameter determined based on the measured current and a second parameter determined based on an SOC of the battery.

[0008] In some embodiments, the processor may determine a coefficient based on at least one of a temperature of the battery, the SOC, and the surface SOC, and determine the first parameter by reflecting the coefficient to the measured current.

[0009] In some embodiments, the battery apparatus may further include a memory configured to store a correspondence relationship between the coefficient and at least one of the temperature of the battery, the SOC, and the surface SOC. In this case, the processor may determine the coefficient based on the correspondence relationship.

[0010] In some embodiments, the processor may determine the second parameter based on a difference between the SOC and the surface SOC that are estimated at a previous time point.

[0011] In some embodiments, the processor may determine a coefficient based on at least one of the temperature of the battery, the SOC, and the surface SOC, and determine the second parameter by reflecting the coefficient to a difference between the SOC and the surface SOC.

[0012] In some embodiments, the battery apparatus may further include a memory configured to store a correspondence relationship between the coefficient and at least one of the temperature of the battery, the SOC, and the surface SOC. In this case, the processor may determine the coefficient based on the correspondence relationship.

[0013] In some embodiments, the processor may estimate the surface SOC at a current time point based on the surface SOC, the first parameter, and the second parameter that are estimated at a previous time point.

[0014] In some embodiments, the processor may reflect a time change between the previous time point and the current time point to the first parameter and the second parameter, respectively.

[0015] In some embodiments, the processor may estimate a terminal voltage of the battery based on the surface SOC, the SOC, and a current of the battery.

[0016] In some embodiments, the processor may estimate an open circuit voltage of the battery based on the surface SOC, estimate an overpotential of the battery based on the SOC and the surface SOC, estimate a voltage due to an ohmic resistance of the battery based on a current of the battery, and estimate the terminal voltage based on the open circuit voltage, the overpotential, and the voltage due to the ohmic resistance.

[0017] In some embodiments, the battery apparatus may further include a memory configured to store a correspondence relationship between the SOC as an input and the open circuit voltage as an output. In this case, the processor may estimate the open circuit voltage using the surface SOC as the input of the correspondence relationship.

[0018] In some embodiments, the processor may estimate the overpotential based on a ratio or difference between the SOC and the surface SOC.

[0019] According to another embodiment, a method of estimating a state of a battery is provided. The method includes determining a first parameter based on a measured current of the battery, determining a second parameter based on an SOC of the battery, and estimating a surface SOC representing a potential at an electrode surface of the battery based on a plurality of parameters including the first parameter and the second parameter.

[0020] In some embodiments, determining the first parameter may include determining a coefficient based on at least one of a temperature of the battery, the SOC, and the surface SOC, and determining the first parameter by reflecting the coefficient to the measured current.

[0021] In some embodiments, determining the second parameter may include determining a coefficient based on at least one of a temperature of the battery, the SOC, or the surface SOC, and determining the second parameter by

reflecting the coefficient to a difference between the SOC and the surface SOC at a previous time point.

[0022] In some embodiments, estimating the surface SOC may include estimating the surface SOC at a current time point based on the surface SOC, the first parameter, and the second parameter that are estimated at a previous time point.

[0023] In some embodiments, the method may further include estimating a first voltage based on the surface SOC, estimating a second voltage based on the SOC and the surface SOC, estimating a third voltage based on the current of the battery, and estimating a voltage, and estimating a terminal voltage of the battery based on the first voltage, the second voltage, and the third voltage.

[0024] According to yet another embodiment, a program configured to be executed by a processor of a battery apparatus and be stored in a recording medium is provided. The program causes the processor to execute determining a first parameter based on a measured current of the battery, determining a second parameter based on an SOC of the battery, and estimating a surface SOC representing a potential at an electrode surface of the battery based on a plurality of parameters including the first parameter and the second parameter.

Advantageous Effects

[0025] According to an embodiment of the present invention, it is possible to accurately estimate the state of the battery not only in a static state of the battery but also in a dynamic state in which charging or discharging is repeated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] FIG. **1** is a drawing showing a battery apparatus according to an embodiment.

[0027] FIG. **2** is a diagram showing a structure of a battery according to an embodiment.

[0028] FIG. **3** is a diagram showing an example of a state change in a battery.

[0029] FIG. **4** is a diagram for explaining surface SOC estimation in a battery management system according to an embodiment.

[0030] FIG. **5** is a diagram showing an example of a correspondence relationship between a temperature/SOC and a kinetics coefficient in a battery according to an embodiment.

[0031] FIG. **6** is a diagram showing an example of a correspondence relationship between a temperature/SOC and a diffusion coefficient in a battery according to an embodiment.

[0032] FIG. **7** is a flowchart showing a surface SOC estimation method in a battery management system according to an embodiment.

[0033] FIG. **8** is a diagram for explaining battery terminal voltage estimation in a battery management system according to an embodiment.

[0034] FIG. **9** is a flowchart showing a battery terminal voltage estimation method in a battery management system according to an embodiment.

[0035] FIG. **10** is a diagram showing an example of a correspondence relationship between an SOC and an open circuit voltage in a battery according to an embodiment.

[0036] FIG. **11** and FIG. **12** are diagrams showing a relationship between a terminal voltage estimated by a battery terminal voltage estimation method according to an embodiment and an actual terminal voltage.

MODES FOR INVENTION

[0037] In the following detailed description, only certain embodiments have been shown and described, simply by way of illustration. As those skilled in the art would realize, the described embodiments may be modified in various different ways, all without departing from the spirit or scope of the present invention. Accordingly, the drawings and description are to be regarded as illustrative in nature and not restrictive. Like reference numerals designate like elements throughout the specification.

[0038] When it is described that an element is "connected" to another element, it should be understood that the element may be directly connected to the other element or connected to the other element through a third element. On the other hand, when it is described that an element is "directly connected" to another element, it should be understood that the element is connected to the other element through no third element.

[0039] As used herein, a singular form may be intended to include a plural form as well, unless the explicit expression such as "one" or "single" is used.

[0040] In flowcharts described with reference to the drawings, the order of operations or steps may be changed, several operations or steps may be merged, a certain operation or step may be divided, and a specific operation or step may not be performed.

[0041] FIG. **1** is a drawing showing a battery apparatus according to an embodiment, FIG. **2** is a diagram showing a structure of a battery according to an embodiment, and FIG. **3** is a diagram showing an example of a state change in a battery.

[0042] Referring to FIG. **1**, a battery apparatus **100** has a structure that can be electrically connected to an external apparatus. When the external apparatus is a load, the battery apparatus **100** is discharged by operating as a power supply that supplies power to the load. When the external apparatus is a charger, the battery apparatus **100** is charged by receiving external power through the charger. The external apparatus operating as the load may be, for example, an electronic device, a mobility apparatus, or an energy storage system (ESS). The mobility apparatus may be, for example, a vehicle such as an electric vehicle, a hybrid vehicle, or a smart mobility.

[0043] The battery apparatus **100** includes a battery **110**, a voltage measuring circuit **120**, a temperature sensor **130**, a current sensor **140**, and a processor **150**.

[0044] The battery **110** is a rechargeable battery. The battery **100** may be, for example, a lithium battery such as a lithium ion battery or a lithium ion polymer battery, or a nickel battery such as a nickel-cadmium (NiCd) battery or a nickel-metal hydride (NiMH) battery. In some embodiments, the battery **100** may be a single battery cell, a battery module including an assembly of a plurality of battery cells or in which a plurality of assemblies are connected in series or parallel, a battery pack in which a plurality of battery modules are connected in series or parallel, or a system in which a plurality of battery packs are connected in series or parallel.

[0045] The voltage measuring circuit **120** measures a voltage of the battery **110**. In some embodiments, the voltage measurement circuit **120** may measure a voltage of each battery cell.

[0046] The temperature sensor **130** measures a temperature of the battery **110**. In some embodiments, the temperature sensor **130** may measure a temperature at a predetermined location of the battery **110**. In some embodiments, a plurality of temperature sensors **130** may be provided to measure temperatures at a plurality of locations in the battery **110**.

[0047] The current sensor **140** is connected to a positive output terminal or negative output terminal of the battery **110**, and measures a current of the battery **110**, i.e., a charging current or a discharging current.

[0048] The processor **150** estimates a state of the battery **110** based on the voltage of the battery **110** measured by the voltage measuring circuit **120**, the temperature of the battery **110** measured by the temperature sensor **130**, or the current of the battery **110** measured by the current sensor **140**. In some embodiments, the battery apparatus **100** may further include a memory **160** that stores data necessary for state estimation in the processor **150**.

[0049] In some embodiments, the processor **150** may form a battery management system. In some embodiments, the battery management system may further include at least one of the voltage measurement circuit **120**, the temperature sensor **130**, or the current sensor **140**.

[0050] Referring to FIG. **2**, the battery **110** includes a positive electrode (or cathode) **111**, a negative electrode (or anode) **112**, and an electrolyte **113**. A structure of the battery **110** shown in FIG. **2** is a schematic example for convenience of description, and the structure of the battery **110** is not limited thereto. In FIG. **2**, for convenience, it is assumed that lithium is an active material causing a chemical reaction in the battery **110**.

[0051] When the battery **110** is discharged in order to supply power from the battery **110** to an external apparatus, as shown in FIG. **2**, a chemical reaction (oxidation reaction) in which a lithium ion Li^+ are discharged from the negative electrode **112** may occur on a surface of the negative electrode **112**. The discharged lithium ion Li^+ may pass through the electrolyte **113** and then move to a surface of the positive electrode **111**. Accordingly, a chemical reaction (reduction reaction) in which the lithium ion Li^+ is absorbed into the positive electrode **111** may occur on the surface of the positive electrode **111**.

[0052] When the battery **110** is charged, a chemical reaction (oxidation reaction) in which a lithium ion Li^+ is discharged from the positive electrode **111** may occur on a boundary surface between the positive electrode **111** and the electrolyte **113**. The discharged lithium ion Li^+ may pass through the electrolyte **113** and then move to the surface of the negative electrode **112**. Accordingly, a chemical reaction (reduction reaction) in which the lithium ion Li^+ is absorbed into the negative electrode **112** may occur on the surface of the negative electrode **112**.

[0053] A terminal voltage of the battery **110** may be appeared in a form of summing a potential at a battery electrode surface corresponding to the positive electrode **111** and the negative electrode **112**, voltage drop due to an ohmic resistance (internal resistance) formed by the electrolyte **113** and the like, and an over-potential due to electrochemical reaction. The overpotential may represent voltage drop occurred by deviation from an equilibrium potential due to polarization at each battery electrode. The overpotential is also called a polarization voltage.

[0054] As shown in FIG. **3**, when the battery **110** starts discharging, the terminal voltage Vt of the battery **110** momentarily drops due to the voltage drop Vohmic by the ohmic resistance Rohmic, and then gradually decreases due to a transient change V1 of the overpotential. In general, the transient change V1 of the overpotential may be expressed as a change depending on a time constant defined in a parallel circuit of a resistor and a capacitor. At this time, the actual terminal voltage Vt of the battery **110** decreases with a constant slope along with the transient change V1 of the overpotential. That is, as shown in FIG. **3**, a decrease Vk according to the constant slope and a decrease V1 according to the transient change of the overpotential appear together. This slope is determined by a magnitude of a current flowing through the battery **110**. As described above, the phenomenon in which the terminal voltage Vt of the battery **110** decreases with the certain slope occurs because concentration of the active material on the electrode surface due to an oxidation/reduction reaction of the active material is lower than an average concentration. That is, the voltage change Vk according to the constant slope may occur by a voltage change (change due to discharging or charging) caused by an oxidation/reduction reaction rate and a voltage change caused by a diffusion resistance (concentration difference) in a relaxation period after the current disappears.

[0055] In general, a state of the battery **110** is determined as a state of charge (SOC) representing an average concentration at the whole of the battery **110**, and the terminal voltage Vt of the battery **110** is estimated based on the open circuit voltage of the battery **110**, the voltage drop (Vohmic) due to the ohmic resistance (Rohmic), and the overpotential. At this time, the open circuit voltage is estimated based on the SOC of the battery **110**. However, the SOC represents the average concentration (e.g., the average concentration at the electrode) inside the battery **110** rather than the concentration on the surface of the battery electrode, and gradually decreases when the battery **110** is discharged as shown in FIG. **3**. Therefore, when the open circuit voltage of the battery **110** is estimated based on the SOC, the terminal voltage of the battery **110** may not be accurately estimated. Accordingly, in some embodiments, a surface state of charge (SOC) capable of determining the potential at the electrode surface of the battery **110** is provided. Such a surface SOC may represent the concentration of the active material on the electrode surface of the battery **110**.

[0056] FIG. **4** is a diagram for explaining surface SOC estimation in a battery management system according to an embodiment, FIG. **5** is a diagram showing an example of a correspondence relationship between a temperature/SOC and a kinetics coefficient in a battery according to an embodiment, and FIG. **6** is a diagram showing an example of a correspondence relationship between a temperature/SOC and a diffusion coefficient in a battery according to an embodiment.

[0057] Referring to FIG. **4**, a processor (e.g., **150** in FIG. **1**) of a battery management system may estimate a surface SOC of a battery (e.g., **110** in FIG. **1**) based on measured information of the battery **110** including a current of the battery **110**, using a surface SOC estimation model **410**. In some embodiments, the surface SOC may be estimated as a percentage. In some embodiments, the processor **150** may

estimate an SOC of the battery **110** representing an average concentration based on the measured information of the battery including the current of the battery **110**, using the surface SOC estimation model **410**.

[0058] As described with reference to FIG. **3**, when the battery **110** is discharged, a terminal voltage of the battery **110** may decrease with a certain slope. Since the phenomenon in which the terminal voltage of the battery **110** decrease with the certain slope occurs because concentration of an active material on an electrode surface decreases by an oxidation/reduction reaction of the active material, the certain slope is proportional to the current of the battery **110**. Accordingly, the surface SOC estimation model **410** may estimate the surface SOC based on the reaction rate determined by the current of the battery **110**. In some embodiments, a reaction rate (kinetics) may be determined based on a value obtained by reflecting a specific coefficient to the current of the battery **110**. Hereinafter, such a specific factor is referred to as a "kinetics coefficient". In one embodiment, the reaction rate may be determined based on a product of the current of the battery **110** and the kinetics coefficient.

[0059] The reaction rate of the oxidation/reduction reaction may be determined by the temperature of the battery **110** and the average concentration inside the battery **110**. Thus, in some embodiments, the kinetics coefficient may vary depending on the temperature of the battery **110** and the SOC of the battery **110**. In one embodiment, the SOC of the battery **110** may include the SOC of the battery **110** representing the average concentration. In another embodiment, the SOC of the battery **110** may include the surface SOC of the battery **110**. In yet another embodiment, the SOC of the battery **110** may include the SOC of the battery **110** representing the average concentration and the surface SOC of the battery **110**. That is, the surface SOC estimation model **410** may determine the kinetics coefficient based on the temperature of the battery **110** and the SOC of the battery **110**. In some embodiments, as shown in FIG. **5**, a correspondence relationship between the temperature/SOC of the battery **110** and the kinetics coefficient may be predefined through experiments. In some embodiments, a memory of the battery management system may store such correspondence relationship, for example, in the form of a lookup table. In some embodiments, the surface SOC estimation model **410** may determine the kinetics coefficient based on either the temperature of the battery **110** or the SOC of the battery **110**.

[0060] When the concentration on the electrode surface is lower than the average concentration by the oxidation/reduction reaction on the electrode surface, a resistance component in which the reaction on the electrode surface is lowered by a diffusion rate caused by a concentration difference between the concentration on the electrode surface and the average concentration may appear. Such a resistance caused by the diffusion (hereinafter referred to as a "diffusion resistance") may be expressed as a force that suppresses the oxidation/reduction reaction in a reverse direction. Therefore, the surface SOC estimation model **410** additionally reflects the diffusion resistance when estimating the surface SOC. In some embodiments, the diffusion resistance may be determined based on a difference between the SOC representing the average concentration and the surface SOC representing the concentration on the electrode surface. In some embodiments, the surface SOC estimation model **410** may estimate the surface SOC based on a value obtained by reflecting a specific coefficient to the difference between the SOC and the surface SOC. Hereinafter, such a specific coefficient is referred to as a "diffusion coefficient". In one embodiment, the surface SOC estimation model **410** may estimate the surface SOC based on a product of the diffusion coefficient and the difference between the SOC and the surface SOC.

[0061] The reaction rate of the oxidation/reduction reaction may be determined based on the temperature of the battery **110** and the average concentration inside the battery **110**. Thus, in some embodiments, the diffusion coefficient that suppresses the oxidation/reduction reaction may vary depending on the temperature of the battery **110** and the SOC of the battery **110**. In one embodiment, the SOC of the battery **110** may include the SOC of the battery **110** representing an average concentration. In another embodiment, the SOC of the battery **110** may include the surface SOC of the battery **110**. In yet another embodiment, the SOC of the battery **110** may include the SOC of the battery **110** representing the average concentration and the surface SOC of the battery **110**. That is, the surface SOC estimation model **410** may determine the diffusion coefficient based on the temperature of the battery **110** and the SOC of the battery **110**. In some embodiments, as shown in FIG. **6**, a correspondence relationship between the temperature/SOC of the battery **110** and the diffusion coefficient may be predefined through experiments. In some embodiments, the memory of the battery management system may store the correspondence relationship, for example, in the form of a lookup table. In some embodiments, the surface SOC estimation model **410** may determine the diffusion coefficient based on either the temperature of the battery **110** or the SOC of the battery **110**.

[0062] In some embodiments, the surface SOC estimation model **410** may estimate the surface SOC at a current time point by reflecting at least a change due to the reaction rate from a previous time point to the current time point and a change due to the diffusion resistance from the previous time point to the current time point to the surface SOC estimated at the previous time point. In some embodiments, the processor **150** may predefine an initial value SSOC[0] of the surface SOC for estimating the surface SOC.

[0063] FIG. **7** is a flowchart showing a surface SOC estimation method in a battery management system according to an embodiment.

[0064] Referring to FIG. **7**, a processor (e.g., **150** in FIG. **1**) inputs measured information of a battery (e.g., **110** in FIG. **1**) to a surface SOC estimation model at S**710**. The measured information of the battery **110** may include a current of the battery **110**. In some embodiments, the current of the battery **110** may be a charging or discharging current of the battery **110** measured by a current sensor (e.g., **140** in FIG. **1**). In some embodiments, the measured information of the battery **110** may further include a measured voltage of the battery **110**. In some embodiments, the measured voltage of the battery **110** may be an average cell voltage, and the average cell voltage may be an average value of voltages of a plurality of battery cells. In some embodiments, the measured voltage of the battery **110** may be a sum of voltages of the plurality of battery cells. In some embodiments, the measured information of the battery **110** may further include a temperature of the battery **110**. In some embodiments, the temperature of the battery **110** may be a temperature measured by a temperature sensor (e.g., **130** in FIG. **1**).

[0065] The processor **150** determines a plurality of parameters at time point t using the surface SOC estimation model at S**720** and S**730**. The plurality of parameters may include a parameter corresponding to a reaction rate and a parameter corresponding to a diffusion resistance.

[0066] The processor **150** determines the reaction rate K[t] of the battery **110** at time point t using the surface SOC estimation model at S**720**. The processor **150** may calculate the reaction rate K[t] as a product Kc*I[t] of a kinetics coefficient Kc and the temperature of the battery **110** at time point t. In some embodiments, the processor **110** may extract the kinetics coefficient Kc corresponding to the temperature of the battery **110** and the SOC of the battery **110** from a memory. In some embodiments, the memory may be a memory (e.g., **160** in FIG. **1**) of a battery management system. In some embodiments, the processor **150** may estimate the SOC of the battery **110** based on the measured information of the battery **110**. In some embodiments, the processor **150** may estimate the SOC using any one of various known methods, and the present invention is not limited to the method of estimating the SOC.

[0067] In addition, the processor **150** determines the diffusion resistance D[t] of the battery **110** at time point t using the surface SOC estimation model at S**730**. The processor **150** may calculate the diffusion resistance D[t] as a product Dc*ΔSOC[t] of a difference ΔSOC[t] between the SOC and the surface SOC at time point t and the diffusion coefficient Dc. In some embodiments, the processor **110** may extract the diffusion coefficient Dc corresponding to the temperature of the battery **110** and the SOC of the battery **110** from the memory. In some embodiments, the memory may be the memory **160** of the battery management system.

[0068] Next, at S**740**, the processor **150** estimates the surface SOC SSOC[t+1] at the time point (t+1) based on the surface SOC SSOC[t], the reaction rate K[t], and the diffusion resistance D[t] estimated at time point t, using the surface SOC estimation model. In some embodiments, the processor **150** may estimate the surface SOC SSOC[t+1] as in Equation 1 or 2.

$$SSOC[t+1]=SSOC[t]+(K[t]+D[t])\cdot\Delta t \quad \text{Equation 1}$$

$$SSOC[t+1]=SSOC[t]+(Kc\cdot I[t]+Dc\cdot\Delta SOC[t])\cdot\Delta t \quad \text{Equation 2}$$

[0069] In Equations 1 and 2, Δt denotes a time change (time difference) between time point (t+1) and time point t.

[0070] In some embodiments, the surface SOC estimation model may accurately estimate the surface SOC by repeatedly performing the estimation of the surface SOC. In some embodiments, an adaptive filter may be used as the surface SOC estimation model.

[0071] According to above-described embodiments, the state of the battery **110** can be accurately estimated by using the surface SOC that can accurately represent the potential of the electrode surface of the battery **110**.

[0072] Next, embodiments of estimating a terminal voltage of the battery **110** using a surface SOC are described with reference to FIG. **8**, FIG. **9**, and FIG. **10**.

[0073] FIG. **8** is a diagram for explaining battery terminal voltage estimation in a battery management system according to an embodiment, FIG. **9** is a flowchart showing a battery terminal voltage estimation method in a battery management system according to an embodiment, and FIG. **10** is a diagram showing an example of a correspondence relationship between an SOC and an open circuit voltage in a battery according to an embodiment.

[0074] Referring to FIG. **8** and FIG. **9**, a processor (e.g., **150** of FIG. **1**) estimates a surface SOC using a surface SOC estimation model (e.g., **410** of FIG. **4**). That is, as described with reference to FIG. **7**, the processor inputs measured information of the battery (**110** in FIG. **1**) to the surface SOC estimation model **410** at S**910**, calculates a reaction rate K[t] and a diffusion resistance D[t] of the battery **110** at S**920** and S**930**, and estimate the surface SOC SSOC[t+1] based on the reaction rate K[t] and the diffusion resistance D[t] at S**940**.

[0075] Next, the processor **150** inputs the SOC, the surface SOC, and a current of the battery **110** to a terminal voltage estimation model **810**, and estimates a terminal voltage of the battery **110** using the terminal voltage estimation model **810**.

[0076] To this end, the processor **150** estimates an open circuit voltage of the battery **110** based on the surface SOC at S**950**. The processor **150** may estimate the open circuit voltage Voc based on a non-linear functional relationship Voc=f(SSOC) between the surface SOC SSOC and the open circuit voltage Voc. In general, a memory (e.g., **160** in FIG. **1**) of the battery management system stores a correspondence relationship between the open circuit voltage Voc of the battery **110** and the SOC of the battery **110** in advance. For example, the correspondence relationship between the open circuit voltage Voc and the SOC may be defined as shown in FIG. **10**. In this case, the processor **150** determines the open circuit voltage Voc by inputting the surface SOC instead of the SOC. For example, when the surface SOC is 70%, the processor **150** may extract an open circuit voltage corresponding to the SOC of 70% from the memory. In some embodiments, the correspondence relationship between the open circuit voltage and the SOC may be stored per temperature. In this case, the processor **150** may determine the open circuit voltage based on the correspondence relationship between the SOC and the open circuit voltage, corresponding to the temperature of the battery **110**, among various correspondence relationships.

[0077] Further, the processor **150** estimates an overpotential due to polarization at S**960**. Since the overpotential is caused by deviation of a potential at an electrode surface from an equilibrium potential, the processor **150** estimates the overpotential based on the surface SOC representing the potential at the electrode surface and the SOC representing the equilibrium potential. In some embodiments, the processor **150** may estimate the overpotential based on a value obtained by comparing the SOC and the surface SOC. In one embodiment, the value obtained by comparing the SOC and the surface SOC may be a ratio of the SOC and the surface SOC. In another embodiment, the value obtained by comparing the SOC and the surface SOC may be a difference between the SOC and the surface SOC. In some embodiments, the processor **150** may estimate the overpotential V1[t+1] at time point (t+1) based on the overpotential V1[t], the SOC SOC[t], and the surface SOC SSOC[t] at time point t, using the terminal voltage estimation model **810**. In some embodiments, the processor **150** may estimate the overpotential V1[t+1], for example, as in Equation 3.

$$V1[t+1]=V1[t]+\alpha\cdot(SOC[t]/SSOC[t]) \quad \text{Equation 3}$$

[0078] In Equation 3, a denotes an overpotential coefficient.

[0079] In some embodiments, the overpotential coefficient α may be determined by experiments. In some embodiments, the overpotential coefficient α may be determined by

repeatedly performing overpotential estimation using an adaptive filter. In some embodiments, the processor **150** may predefine an initial value V1[0] of the overpotential for estimating the overpotential.

[0080] In addition, the processor **150** estimates a voltage due to an ohmic resistance of the battery **110** at S**970**. The processor **150** estimates the voltage Vohmic due to the ohmic resistance as a product of the ohmic resistance of the battery **110** and the current of the battery **110**. In some embodiments, the processor **150** may estimate the ohmic resistance using any one of various known methods, and the present invention is not limited to the method for estimating the ohmic resistance.

[0081] Next, the processor **150** determines the terminal voltage of the battery **110** based on the open circuit voltage Voc, the overpotential V1, and the voltage Vohmic due to the ohmic resistance at S**980**. In some embodiments, as shown in Equation 4, the processor **150** may determine a sum of the open circuit voltage Voc, the overpotential V1, and the voltage Vohmic by the ohmic resistance as the terminal voltage Vt of the battery **110**.

$$Vt=Voc+V1+\text{Vohmic} \qquad \text{Equation 4}$$

[0082] While the surface SOC estimating method or the terminal voltage estimating method has been described in a case of discharging the battery, the surface SOC estimating method or the terminal voltage estimating method according to above-described embodiments may be applied to a case of charging the battery. As shown in FIG. **3**, in the discharging, the surface SOC representing the surface concentration appears lower than the SOC representing the average concentration, whereas in the charging, the surface SOC may appear higher than the SOC.

[0083] FIG. **11** and FIG. **12** are diagrams showing a relationship between a terminal voltage estimated by a battery terminal voltage estimation method according to an embodiment and an actual terminal voltage. FIG. **11** and FIG. **12** show an estimated terminal voltage and an actual terminal voltage when a surface SOC is 5%, 60%, and 100%, FIG. **11** shows the terminal voltage during charging of the battery, and FIG. **12** shows the terminal voltage during discharging of the battery.

[0084] As shown in FIG. **11** and FIG. **12**, it can be seen that the terminal voltage (solid line) estimated by the battery terminal voltage estimation method according to an embodiment changes similarly to the actual terminal voltage (dashed line).

[0085] According to the above-described embodiments, by estimating the surface SOC representing the potential at the electrode surface based on the current of the battery and the oxidation/reduction reaction of the active material, it is possible to accurately estimate the state of the battery not only in a static state of the battery but also in a dynamic state in which charging or discharging is repeated.

[0086] In some embodiments, a processor (e.g., **150** of FIG. **1**) may perform computation on a program for executing the surface SOC estimation method or terminal voltage estimation method described above. A program for executing the surface SOC estimation method or the terminal voltage estimation method may be loaded into a memory. The memory may be the same memory as a memory (e.g., **160** in FIG. **1**) for storing a table or a separate memory. The program may include instructions for causing the processor **150** to perform the surface SOC estimation method or the terminal voltage estimation method when loaded into a memory. That is, the processor may perform an operation for the surface SOC estimation method or the terminal voltage estimation method by executing the instructions of the program.

[0087] While this invention has been described in connection with what is presently considered to be practical embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. On the contrary, it is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

1. A battery apparatus, comprising:
a battery; and
a processor configured to:
receive a measured current of the battery; and
estimate a surface state of charge (SOC) representing a potential at an electrode surface of the battery based on a plurality of parameters, the plurality of parameters including a first parameter determined based on the measured current and a second parameter determined based on a state of charge (SOC) of the battery.

2. The battery apparatus of claim **1**, wherein the processor is further configured to:
determine a coefficient based on at least one of a temperature of the battery, the SOC, and the surface SOC; and
determine the first parameter by reflecting the coefficient to the measured current.

3. The battery apparatus of claim **2**, further comprising a memory configured to store a correspondence relationship between the coefficient and at least one of the temperature of the battery, the SOC, and the surface SOC,
wherein the processor is further configured to determine the coefficient based on the correspondence relationship.

4. The battery apparatus of claim **1**, wherein the processor is further configured to determine the second parameter based on a difference between the SOC and the surface SOC that are estimated at a previous time point.

5. The battery apparatus of claim **4**, wherein the processor is further configured to:
determine a coefficient based on at least one of a temperature of the battery, the SOC, and the surface SOC; and
determine the second parameter by reflecting the coefficient to a difference between the SOC and the surface SOC.

6. The battery apparatus of claim **5**, further comprising a memory configured to store a correspondence relationship between the coefficient and at least one of the temperature of the battery, the SOC, and the surface SOC,
wherein the processor is further configured to determine the coefficient based on the correspondence relationship.

7. The battery apparatus of claim **1**, wherein the processor is further configured to estimate the surface SOC at a current time point based on the surface SOC, the first parameter, and the second parameter that are estimated at a previous time point.

8. The battery apparatus of claim **7**, wherein the processor is further configured to reflect a time change between the

previous time point and the current time point to the first parameter and the second parameter, respectively.

9. The battery apparatus of claim **1**, wherein the processor is further configured to estimate a terminal voltage of the battery based on the surface SOC, the SOC, and a current of the battery.

10. The battery apparatus of claim **9**, wherein the processor is further configured to:

estimate an open circuit voltage of the battery based on the surface SOC;

estimate an overpotential of the battery based on the SOC and the surface SOC;

estimate a voltage due to an ohmic resistance of the battery based on the measured current of the battery; and

estimate the terminal voltage based on the open circuit voltage, the overpotential, and the voltage due to the ohmic resistance.

11. The battery apparatus of claim **10**, further comprising a memory configured to store a correspondence relationship between the SOC as an input and the open circuit voltage as an output,

wherein the processor is further configured to estimate the open circuit voltage using the surface SOC as the input of the correspondence relationship.

12. The battery apparatus of claim **10**, wherein the processor is further configured to estimate the overpotential based on a ratio or difference between the SOC and the surface SOC.

13. A method of estimating a state of a battery, the method comprising:

determining a first parameter based on a measured current of the battery;

determining a second parameter based on a state of charge (SOC) of the battery; and

estimating a surface state of charge (SOC) representing a potential at an electrode surface of the battery based on a plurality of parameters, the plurality of parameters including the first parameter and the second parameter.

14. The method of claim **13**, wherein the determining of the first parameter includes:

determining a coefficient based on at least one of a temperature of the battery, the SOC, and the surface SOC; and

determining the first parameter by reflecting the coefficient to the measured current.

15. The method of claim **13**, wherein the determining of the second parameter includes:

determining a coefficient based on at least one of a temperature of the battery, the SOC, or the surface SOC; and

determining the second parameter by reflecting the coefficient to a difference between the SOC and the surface SOC at a previous time point.

16. The method of claim **13**, wherein the estimating of the surface SOC includes estimating the surface SOC at a current time point based on the surface SOC, the first parameter, and the second parameter that are estimated at a previous time point.

17. The method of claim **13**, further comprising:

estimating a first voltage based on the surface SOC;

estimating a second voltage based on the SOC and the surface SOC;

estimating a third voltage based on the measured current of the battery; and

estimating a terminal voltage of the battery based on the first voltage, the second voltage, and the third voltage.

18. A program configured to be executed by a processor of a battery apparatus and stored in a non-transitory recording medium, wherein the program causes the processor to execute:

determining a first parameter based on a measured current of the battery;

determining a second parameter based on a state of charge (SOC) of the battery; and

estimating a surface state of charge (SOC) representing a potential at an electrode surface of the battery based on a plurality of parameters, the plurality of parameters including the first parameter and the second parameter.

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