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(54) **METHOD AND APPARATUS FOR MEASURING STATE OF BATTERY**

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(52) **U.S. Cl.**

CPC ***G01R 31/367*** (2019.01); ***G01R 31/387*** (2019.01); ***G01R 31/392*** (2019.01)

(57) **ABSTRACT**

Disclosed is a method and apparatus for measuring a battery state. The method includes determining an operational mode of a battery; measuring a battery state of the battery using an electrochemical model in response to the battery determined to be operating in a low rate mode, and measuring the battery state using a modified electrochemical model based on a characteristic of the battery, in response to the battery determined to be operating in a high rate mode.

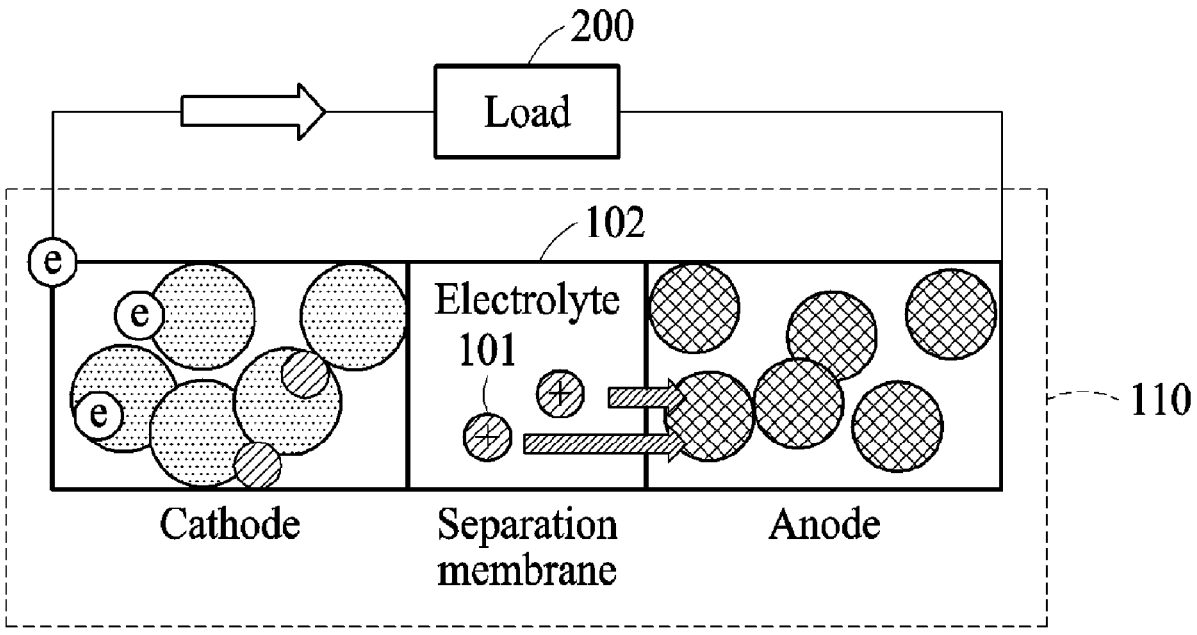


FIG. 1

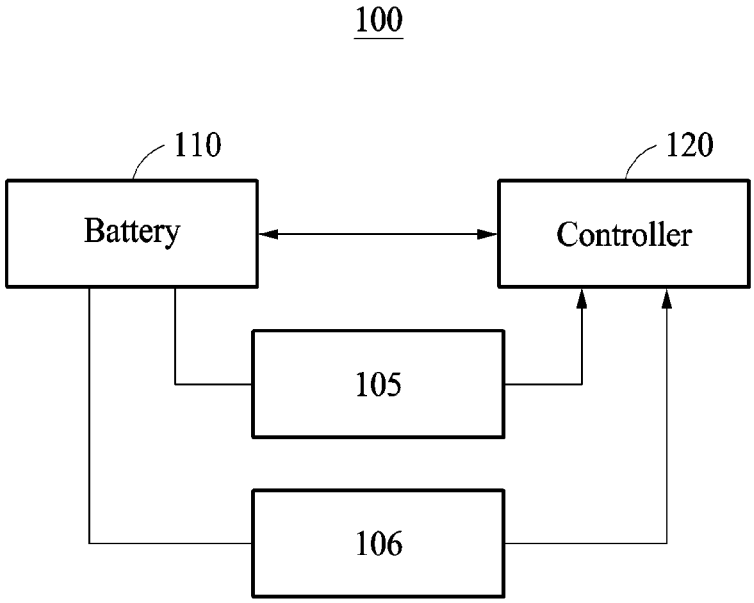

100
110
120
Battery
Controller
105
106

FIG. 2

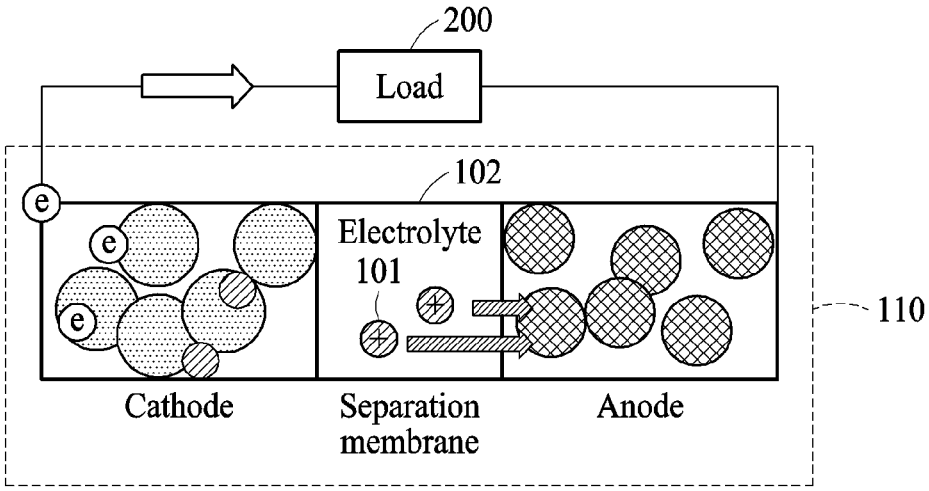

200
Load
102
e
e
e
Electrolyte
101
110
Cathode
Separation membrane
Anode

FIG. 3A

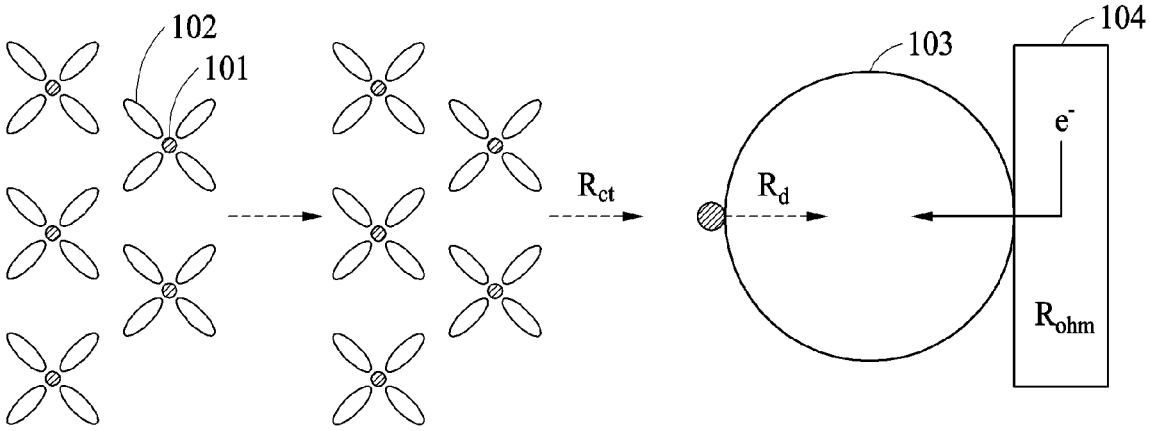


FIG. 3B

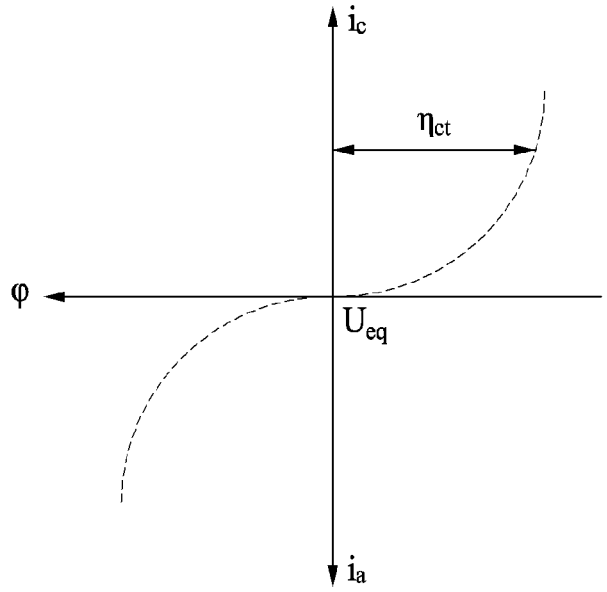


FIG. 4A

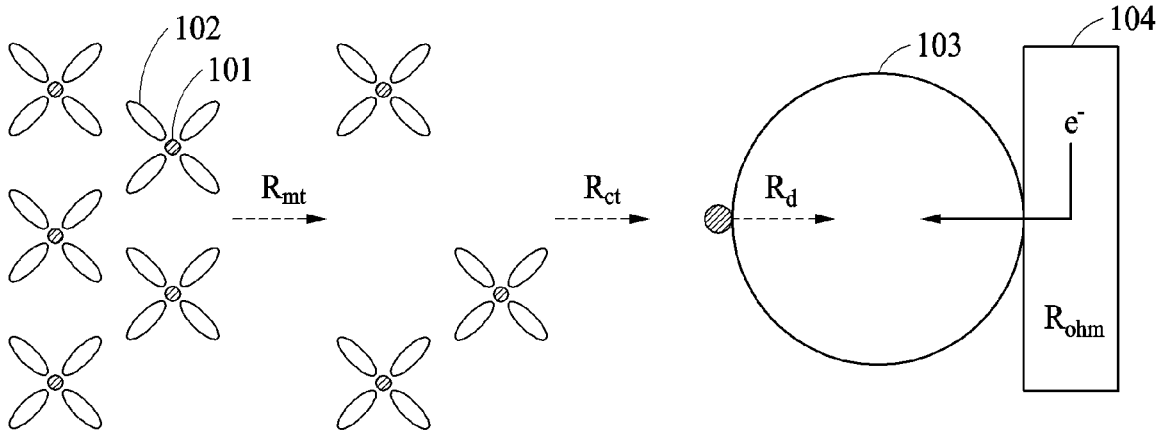


FIG. 4B

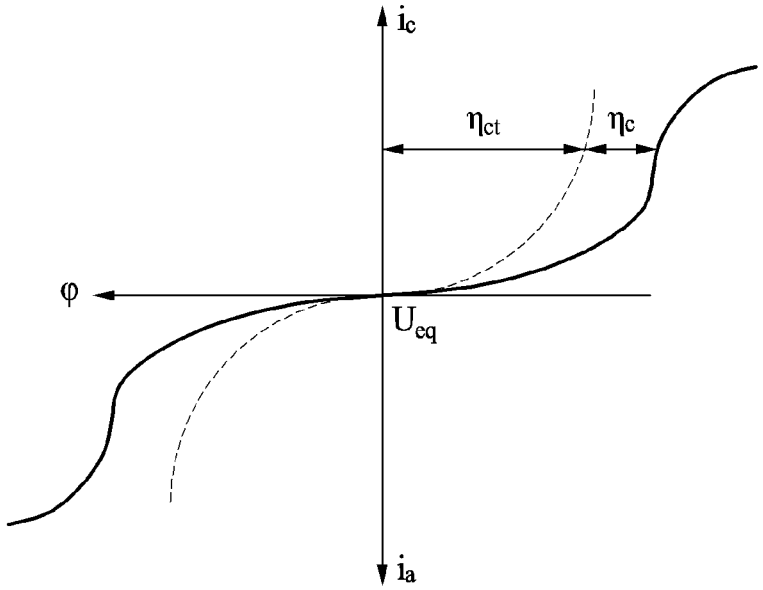


FIG. 5

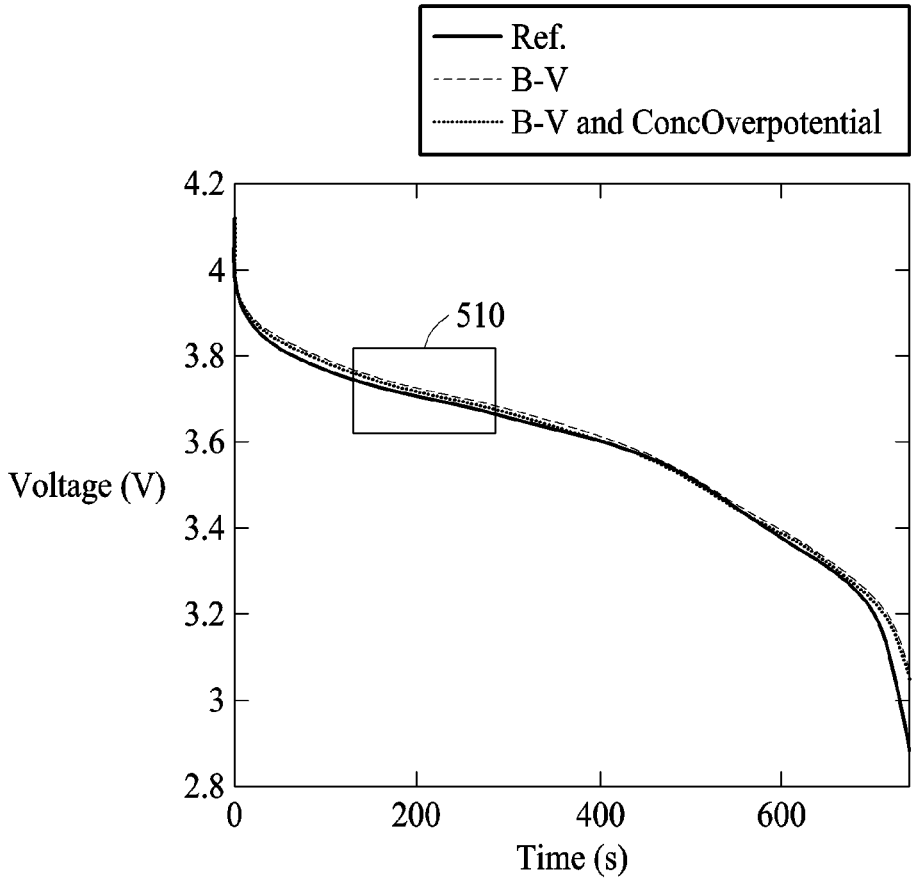

Ref.
B-V
B-V and ConcOverpotential
510
Voltage (V)
4.2
4
3.8
3.6
3.4
3.2
3
2.8
0
200
400
600
Time (s)

FIG. 6

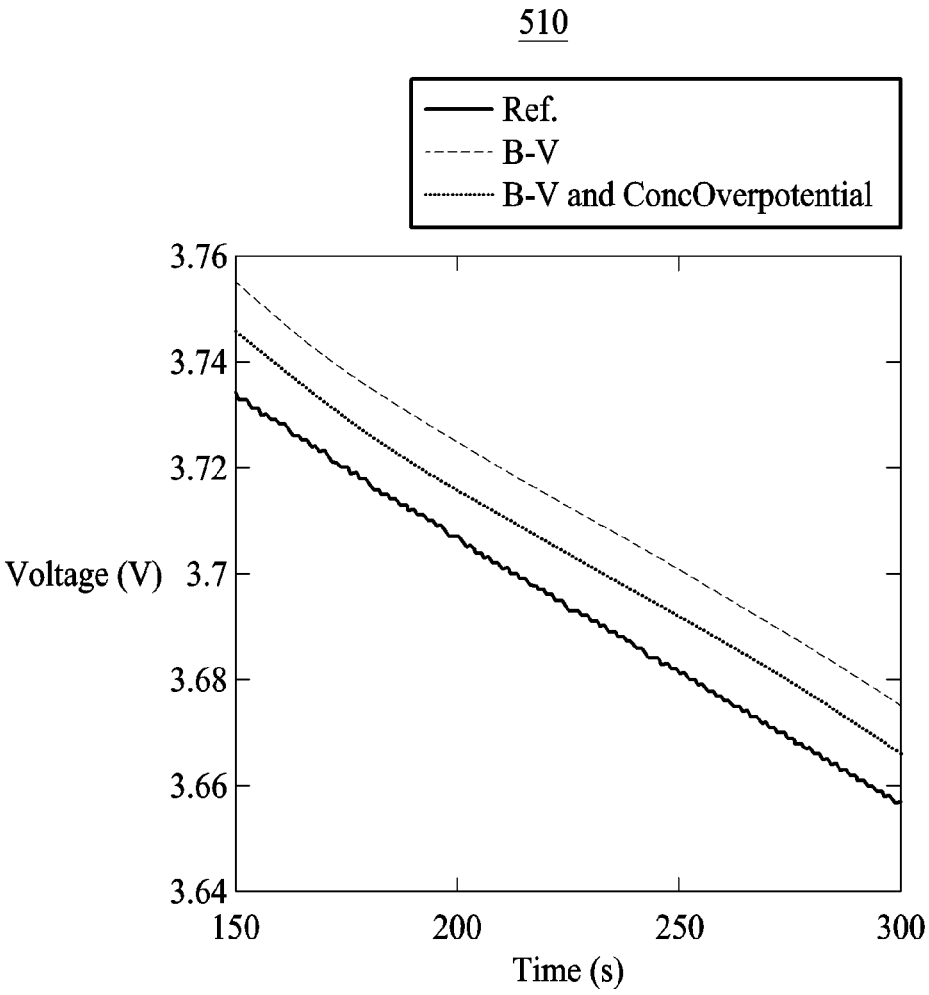

510
Ref.
B-V
B-V and ConcOverpotential
3.76
3.74
3.72
3.7
3.68
3.66
3.64
Voltage (V)
150
200
250
300
Time (s)

FIG. 7

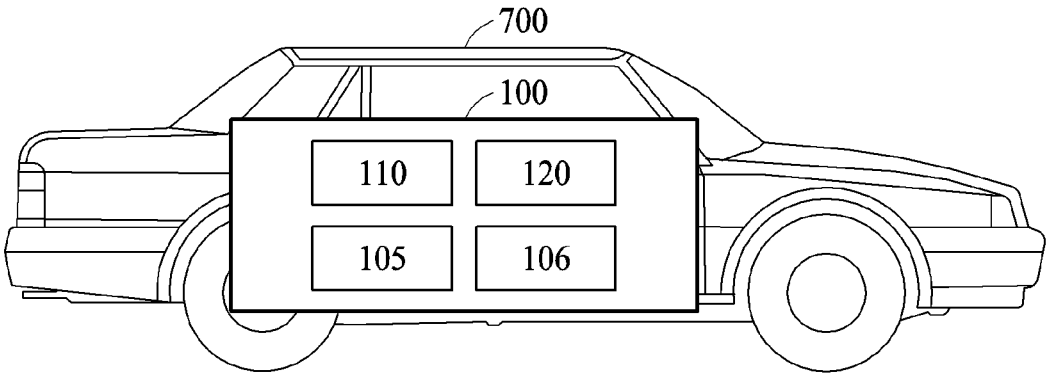
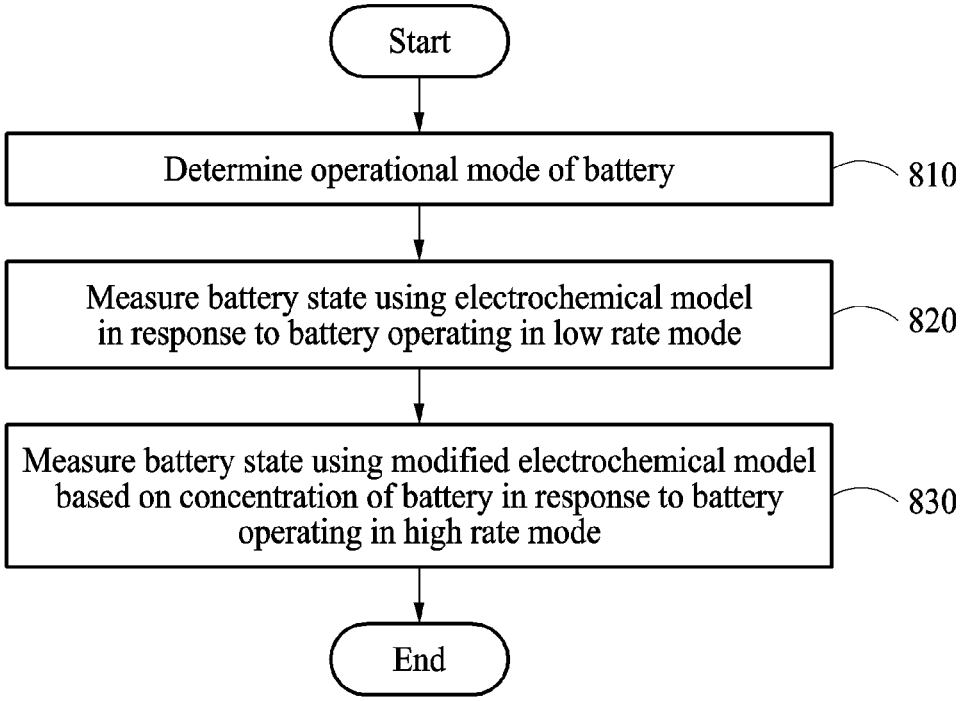

700
100
110
120
105
106

FIG. 8


Start
Determine operational mode of battery
810
Measure battery state using electrochemical model in response to battery operating in low rate mode
820
Measure battery state using modified electrochemical model based on concentration of battery in response to battery operating in high rate mode
830
End

METHOD AND APPARATUS FOR MEASURING STATE OF BATTERY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Continuation Application of U.S. patent application Ser. No. 15/894,682 filed on Feb. 12, 2018, which claims the benefit under 35 USC § 119(a) of Korean Patent Application No. 10-2017-0140185 filed on Oct. 26, 2017, in the Korean Intellectual Property Office, the entire disclosure of which is incorporated herein by reference for all purposes.

BACKGROUND

1. Field

[0002] This Application relates to a method and apparatus for measuring a battery state of a battery.

2. Description of the Background

[0003] To stably use a battery to the maximum capacity of the battery, it is important to accurately estimate a current state of the battery. The battery state may include a state of charge (SOC), a state of health (SOH), and the like.

[0004] Various methods may be used to estimate a battery state. The various methods may include, for example, a current counting method, a voltage measurement method, and a resistance measurement method.

[0005] The current counting method, for example, an Ah counting method or a Coulomb counting method, refers to a method of estimating an SOC by applying a used capacity based on a relationship between a current and a time.

[0006] The voltage measurement method refers to a method of estimating a state of a battery based on a relationship between an SOC and an open circuit voltage (OCV) that is measured in advance from an OCV of the battery. For example, the voltage measurement method may calculate the SOC by referring to a lookup table in which the OCV and the SOC are provided to correspond to each other.

[0007] The resistance measurement method refers to a method of estimating a state of a battery based on a relationship between an SOC and an internal resistance of the battery. For example, the resistance measurement method may calculate the SOC by referring to a lookup table in which the internal resistance and the SOC are provided to correspond to each other.

[0008] The above information disclosed in this Background section is only for enhancement of understanding of the background of the disclosure and therefore it may contain information that does not form any part of the prior art nor what the prior art may suggest to a person of ordinary skill in the art.

SUMMARY

[0009] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0010] In one general aspect, a method of measuring a battery state includes determining an operational mode of a battery, measuring a battery state of the battery using an electrochemical model in response to the battery determined to be operating in a low rate mode, and measuring the battery state using a modified electrochemical model based on a characteristic of the battery in response to the battery determined to be operating in a high rate mode.

[0011] The battery state may include a state of charge (SOC) of the battery.

[0012] The determining may include determining the operational mode based on a current value output from the battery.

[0013] The determining of the operational mode based on the current value may include calculating a current rate (C-rate) based on the current value; and determining the operational mode based on the C-rate.

[0014] The determining of the operational mode based on the C-rate may include determining that the battery is operating in the high rate mode in response to the C-rate being greater than or equal to a first preset reference value; and determining that the battery is operating in the low rate mode in response to the C-rate being less than the first preset reference value.

[0015] The determining of the operational mode based on the C-rate may further include acquiring a voltage value of the battery; and determining that the battery is operating in the high rate mode in response to the C-rate being less than the first preset reference value and the voltage value being greater than or equal to a second preset reference value.

[0016] The measuring of the battery state using the electrochemical model may include measuring the battery state using a Butler-Volmer's equation for determining an electrochemical reaction amount on an interface between an electrode and an electrolyte.

[0017] The measuring of the battery state using the modified electrochemical model may include measuring the battery state using a modified Butler-Volmer's equation based on the characteristic of the battery.

[0018] The characteristic of the battery may include the concentration of the battery.

[0019] The concentration of the battery may include the concentration overvoltage of the battery.

[0020] The determining may include measuring a temperature of the battery; and determining that the battery is operating in the high rate mode in response to the temperature being less than a third preset reference value.

[0021] In another general aspect, an apparatus for measuring a battery state includes a battery, and a controller configured to determine an operational mode of the battery, to measure the battery state using an electrochemical model in response to the battery determined to be operating in a low rate mode, and to measure the battery state using a modified electrochemical model based on concentration of the battery, in response to the battery determined to be operating in a high rate mode.

[0022] The battery state may include an SOC of the battery.

[0023] The apparatus for measuring a battery state may further include a first sensor configured to measure a current value output from the battery. The controller may be configured to determine the operational mode based on the current value output from the battery.

[0024] The controller may be configured to calculate a C-rate based on the current value, and to determine the operational mode based on the C-rate.

[0025] The controller may be configured to determine that the battery is operating in the high rate mode in response to the C-rate being greater than or equal to a first preset reference value, and to determine that the battery is operating in the low rate mode in response to the C-rate being less than the first preset reference value.

[0026] The sensor may be configured to acquire a voltage value of the battery, and the controller may be configured to determine that the battery is operating in the high rate mode in response to the C-rate being less than the first preset reference value and the voltage value being greater than or equal to a second preset reference value.

[0027] The controller may be configured to measure the battery state using a Butler-Volmer's equation for determining an electrochemical reaction amount on an interface between an electrode and an electrolyte in response to the battery operating in the low rate mode.

[0028] The controller may be configured to measure the battery state using a modified Butler-Volmer's equation based on the characteristic of the battery in response to the battery operating in the high rate mode.

[0029] The characteristic of the battery may include the concentration of the battery.

[0030] The concentration of the battery may include the concentration overvoltage of the battery.

[0031] The apparatus for measuring a battery state may further include a second sensor configured to measure a temperature of the battery. The controller may be configured to determine that the battery is operating in the high rate mode in response to the temperature being less than a third preset reference value.

[0032] Other features and aspects will be apparent from the following detailed description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] FIG. **1** illustrates a first example of a battery state measurement apparatus.

[0034] FIG. **2** illustrates an example of a configuration of a battery of FIG. **1**.

[0035] FIG. **3**A illustrates an example of a low rate mode of a battery.

[0036] FIG. **3**B illustrates an example of a graph showing a low rate mode of a battery.

[0037] FIG. **4**A illustrates an example of a high rate mode of a battery.

[0038] FIG. **4**B illustrates an example of a graph showing a high rate mode of a battery.

[0039] FIG. **5** illustrates an example of a graph describing performance of a battery state measurement apparatus.

[0040] FIG. **6** illustrates an example of an enlarged partial section of the graph of FIG. **5**.

[0041] FIG. **7** illustrates a second example of a battery state measurement apparatus.

[0042] FIG. **8** is a flowchart illustrating an example of a method of measuring a state of a battery.

[0043] Throughout the drawings and the detailed description, the same drawing reference numerals refer to the same elements. The drawings may not be to scale, and the relative size, proportions, and depiction of elements in the drawings may be exaggerated for clarity, illustration, and convenience.

DETAILED DESCRIPTION

[0044] The following detailed description is provided to assist the reader in gaining a comprehensive understanding of the methods, apparatuses, and/or systems described herein. However, various changes, modifications, and equivalents of the methods, apparatuses, and/or systems described herein will be apparent after an understanding of the disclosure of this application. For example, the sequences of operations described herein are merely examples, and are not limited to those set forth herein, but may be changed as will be apparent after an understanding of the disclosure of this application, with the exception of operations necessarily occurring in a certain order. Also, descriptions of features that are known in the art may be omitted for increased clarity and conciseness.

[0045] The features described herein may be embodied in different forms, and are not to be construed as being limited to the examples described herein. Rather, the examples described herein have been provided merely to illustrate some of the many possible ways of implementing the methods, apparatuses, and/or systems described herein that will be apparent after an understanding of the disclosure of this application.

[0046] Although terms of "first" or "second" are used to explain various components, the components are not limited to the terms. These terms should be used only to distinguish one component from another component. For example, a "first" component may be referred to as a "second" component, or likewise, and the "second" component may be referred to as the "first" component within the scope of the right according to the concept of the present disclosure.

[0047] It will be understood that when a component is referred to as being "connected to" another component, the component can be directly connected or coupled to the other component or intervening components may be present.

[0048] As used herein, the singular forms are intended to include the plural forms as well, unless the context clearly indicates otherwise. It should be further understood that the terms "comprises/includes" and/or "comprising/including," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, components or a combination thereof, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0049] Unless otherwise defined herein, all terms used herein including technical or scientific terms have the same meanings as those generally understood by one of ordinary skill in the art. Terms defined in dictionaries generally used should be construed to have meanings matching with contextual meanings in the related art and are not to be construed as an ideal or excessively formal meaning unless otherwise defined herein.

[0050] FIG. **1** illustrates a first example of a battery state measurement apparatus.

[0051] Referring to FIG. **1**, a battery state measurement apparatus **100** measures a battery state of a battery **110**. Here, the battery state includes, for example, a state of charge (SOC), a state of health (SOH), and the like.

[0052] The battery state measurement apparatus **100** may be configured in any type of device using electric energy. For example, the battery state measurement apparatus **100** may be provided in an energy storage system (ESS), an electronic device, a transportation device, and the like. The battery **110**

of the battery state measurement apparatus **100** may function as a power source for elements that constitute the electronic device, the transportation device, and the like.

[0053] In an example in which the battery state measurement apparatus **100** is provided in the transportation device, for example, a vehicle, the battery state measurement apparatus **100** may be provided in, for example, a smart mobility, an electric vehicle, a hybrid vehicle, and a plug-in hybrid vehicle.

[0054] The battery **110** includes one or more battery cells. For example, the battery cell may indicate a secondary cell. The battery **110** may include the battery cell, a battery module, or a battery pack. The battery pack may include one or more battery modules. The battery module may include one or more battery cells.

[0055] The controller **120** measures a battery state of the battery **110**.

[0056] When the battery **110** is configured as the battery pack or the battery module, the controller **120** is understood as a battery management system (BMS). That is, the controller **120** may include a master BMS (M-BMS) and one or more slave BMSs (S-BMSs).

[0057] When the battery **110** is configured as the battery pack, one or more S-BMSs measure a battery state of one or more battery modules. That is, the one or more S-BMSs may be connected to the one or more battery modules, respectively. The one or more S-BMSs transmit the measured battery state to the M-BMS.

[0058] The M-BMS measures a battery state of the battery pack based on the battery state received from the one or more S-BMSs. That is, the M-BMS may measure a battery state of the battery module and the battery state of the battery pack.

[0059] The same principle is applicable to an example in which the battery **110** is configured as the battery module. One or more S-BMSs measure a battery state of one or more battery cells. That is, the one or more S-BMSs may be connected to the one or more battery cells, respectively. The one or more S-BMSs transmit the measured battery state to the M-BMS.

[0060] The M-BMS measures a battery state of the battery module based on the battery state received from the one or more S-BMSs. That is, the M-BMS measures a battery state of the battery cell and the battery state of the battery module.

[0061] The controller **120** measures the battery state of the battery **110** based on an electrochemical model of the battery **110**. The electrochemical model may be a method of calculating internal concentration and potential information of the battery **110** based on physical characteristics of the battery **110** and estimating a residual charge amount of the battery **110**. The controller **120** measures the battery state based on the electrochemical model and may provide internal state information, for example, concentration, potential, and current density, of the battery **110**. The controller **120** may minimize degradation of the battery **110** using an available output predicting function, a fast charging function, and a fast discharging function, etc., of the battery **110**.

[0062] The controller **120** determines an operational mode of the battery **110** and measures the battery state based on a result of the determination.

[0063] The battery **110** may operate in a low rate mode or a high rate mode. The battery **110** operates in the low rate mode when the battery **110** performs a general operation, such as charging, discharging, etc. The battery **110** operates in the high rate mode when the battery **110** performs an operation such as fast charging, fast discharging, etc.

[0064] The operational mode of the battery **110** is classified into the high rate mode or the low rate mode based on an output current value. Accordingly, the controller **120** determines the operational mode of the battery **110** based on the current value output from the battery **110**.

[0065] The battery state measurement apparatus **100** further includes a first sensor **105**. The first sensor **105** measures a current value output from the battery **110** or a voltage value of the battery **110**. For example, the voltage value of the battery **110** indicates an open circuit voltage (OCV). The first sensor **105** outputs the measured current value or voltage value to the controller **120**.

[0066] The controller **120** calculates a current rate (C-rate) of the battery **110** based on the current value output from the battery **110**. The C-rate refers to a value acquired by dividing charging current or discharging current of the battery **110** by a rated capacity value of the battery **110**. For example, when a battery cell having the rated capacity value of 10 Ah discharges the current of 10 A, the C-rate is 1C. When the battery cell discharges the current of 20 A, the C-rate is 2C. Based on the same principle, when a battery cell having the rated capacity value of 100 Ah discharges the current of 100 A, the C-rate is 1C. When the battery cell discharges the current of 200 A, the C-rate is 2C.

[0067] The controller **120** determines an operational mode of the battery **110** based on the C-rate. When the C-rate is greater than or equal to a first reference value, the controller **120** determines that the battery **110** is operating in the high rate mode. When the C-rate is less than the first reference value, the controller **120** determines that the battery **110** is operating in the low rate mode. For example, the first reference value may be 2C. The first reference value may be preset based on a number of battery cells or a number of battery modules.

[0068] When the C-rate is less than the first reference value and the voltage value is greater than or equal to a second reference value, the controller **120** determines that the battery **110** is operating in the high rate mode. The second reference value may be a value preset by a user. The user may set the second reference value based on an accuracy of the battery state measurement apparatus **100**.

[0069] When a difference between an actual voltage value and the voltage value measured by the first sensor **105** is greater than or equal to the second reference value, the controller **120** determines that the battery **110** is operating in the high rate mode.

[0070] When the battery **110** operates in the low rate mode, the controller **120** measures the battery state using the electrochemical model of the battery **110**. The electrochemical model may include a Butler-Volmer's equation. The controller **120** may enhance the accuracy of the determination of the battery state using a charge conservation law and a mass conservation law. For example, the controller **120** enhances the accuracy of the determination of the battery state using a Butler-Volmer's equation for determining an electrochemical reaction amount on an interface between an electrode and an electrolyte.

[0071] Hereinafter, an operation of the controller **120** that measures the battery state using the Butler-Volmer's equation will be described with reference to the following equations. Equation 1 may be used to calculate an activation overvoltage η_t of the battery **110**. The activation overvoltage

η_i of Equation 1 may be equal to an activation overvoltage η_{ct} of FIG. **3**B. An equilibrium potential $U_{i,ref}$ of Equation 1 may be equal to an equilibrium potential U_{eq} of FIG. **3**B.

$$\eta_i = \varphi_s - \varphi_e - U_{i,ref} - \frac{j^{Li}}{a_{s,i}} R_{f,i},\ i = n,\ p \tag{1}$$

[0072] In Equation 1, η_i denotes an activation overvoltage [V], φ_s denotes a solid potential (or electrode potential) [V], φ_e denotes an electrolyte potential [V], $U_{i,ref}$ denotes an equilibrium potential [V], j^{Li} denotes a current density [A/m^3], $a_{s,i}$ denotes a specific surface area [1/m] representing a surface area over volume of an electrode active material, $R_{f,i}$ denotes a film resistance [$\Omega \cdot m^2$], and i denotes a reaction in an anode or a negative electrode (n) or a reaction in a cathode or a positive electrode (p). That is, Equation 1 may indicate the reaction in the anode or the reaction in the cathode depending on whether i is n or p. The electrode active material generates electric energy through a chemical reaction in response to charging or discharging of the battery **110**.

[0073] An exchange current density of the battery **110** may be calculated according to Equation 2.

$$i_{0,i} = k_i (c_{s,i}^{max} - c_{s,i})^{\alpha_{a,i}} c_{s,i}^{\alpha_{c,i}} c_{e,i}^{\alpha_{a,i}}, i = n, p \tag{2}$$

[0074] In Equation 2, $i_{0,i}$ denotes an exchange current density [A/m^2], k_i denotes a reaction constant, $c_{s,i}$ denotes a surface concentration [mol/m^3], $c_{s,i}^{max}$ denotes maximum surface concentration [mol/m^3], $\alpha_{a,i}$ denotes a charge transfer coefficient in the anode, $\alpha_{c,i}$ denotes a charge transfer coefficient in the cathode, $c_{e,i}$ denotes an electrolyte concentration [mol/m3], and i denotes a reaction in the anode (n) or a reaction in the cathode (p). That is, Equation 2 may indicate the reaction in the anode or the reaction in the cathode depending on whether i is n or p.

[0075] The controller **120** is configured to replace Equation 1 and Equation 2 for the Butler-Volmer's equation. The Butler-Volmer's equation is represented as shown in Equation 3.

$$j^{Li} = a_{s,i} i_{0,i} \left[\exp\left(\frac{\alpha_{a,i} F}{RT} \eta_i \right) - \exp\left(-\frac{\alpha_{c,i} F}{RT} \eta_i \right) \right],\ i = n,\ p \tag{3}$$

[0076] In Equation 3, j^{Li} denotes a current density [A/m^3], $a_{s,i}$ denotes a specific surface area [1/m] representing a surface area over volume of an electrode active material, $i_{0,i}$ denotes an exchange current density [A/m^2], $\alpha_{a,i}$ denotes a charge transfer coefficient in the anode, F denotes Faraday's constant [C/mol], R denotes a universal gas constant [J/(mol·K)], T denotes a temperature [K], η_i denotes an activation overvoltage [V], $\alpha_{c,i}$ denotes a charge transfer coefficient in the cathode, and i denotes the reaction in the anode (n) or the reaction in the cathode (p). That is, Equation 3 indicates the reaction in the anode or the reaction in the cathode depending on whether i is n or p.

[0077] The controller **120** calculates the current density j^{Li} from Equation 1 to Equation 3 using a Newton-Raphson method.

[0078] The controller **120** calculates the solid potential φ_s and the electrolyte potential φ_e using the charge conservation law.

[0079] The controller **120** calculates the surface concentration and $c_{s,i}$ the electrolyte concentration $c_{e,i}$ using the mass conservation law.

[0080] The controller **120** measures the battery state based on the current density j^{Li}, the solid potential φ_s the electrolyte potential φ_e, the surface concentration $c_{s,i}$ and the electrolyte concentration $c_{e,i}$.

[0081] When the battery **110** operates in the high rate mode, the controller **120** measures the battery state using a modified electrochemical model based on the concentration of the battery **110**. For example, the concentration of the battery refers to the concentration overvoltage. The modified electrochemical model includes a modified Butler-Volmer's equation based on the concentration of the battery **110**. The controller **120** enhances the accuracy of the determination of the battery state using the charge conservation law and the mass conservation law.

[0082] Hereinafter, an operation of the controller **120** that measures the battery state using the modified Butler-Volmer's equation will be described with reference to the following equations. Equation 4 is used to calculate an overvoltage of the battery **110**. The overvoltage of Equation 4 includes an activation overvoltage η_i and a concentration overvoltage $\eta_{conc,i}$. The concentration overvoltage of Equation 4 may be equal to a concentration overvoltage η_c of FIG. **4**B.

$$\eta_i + \eta_{conc,i} = \varphi_s - \varphi_e - U_{i,ref} - \frac{j^{Li}}{a_{s,i}} R_{f,i},\ i = n,\ p \tag{4}$$

[0083] In Equation 4, η_i denotes an activation overvoltage [V], $\eta_{conc,i}$ denotes a concentration overvoltage [V], φ_s denotes a solid potential [V], φ_e denotes an electrolyte potential [V], $U_{i,ref}$ denotes an equilibrium potential [V], j^{Li} denotes a current density [A/m^3], $a_{s,i}$ denotes a specific surface area [1/m] representing a surface area over volume of an electrode active material, $R_{f,i}$ denotes a film resistance [$\Omega \cdot m^2$], and i denotes a reaction in the anode (n) or a reaction in the cathode (p). That is, Equation 4 indicates the reaction in the anode or the reaction in the cathode depending on whether i is n or p.

[0084] The concentration overvoltage may be calculated according to Equation 5.

$$\eta_{conc,i} = -\frac{RT}{\alpha F} \ln\left(1 - \frac{j^{Li}}{j_{lim}^{Li}} \right),\ i = n,\ p \tag{5}$$

[0085] In Equation 5, $\eta_{conc,i}$ denotes a concentration overvoltage [V], R denotes a universal gas constant [J/(mol·K)], T denotes a temperature [K], α denotes a charge transfer coefficient, F denotes a Faraday's constant [C/mol], j^{Li} denotes a current density [A/m^3], j_{lim}^{Li} denotes a limit current density [A/m^3], and i denotes a reaction in the anode (n) or a reaction in the cathode (p). That is, Equation 5 indicates the reaction in the anode or the reaction in the cathode depending on whether i is n or p. The charge transfer coefficient α may be equal to the charge transfer coefficient $\alpha_{a,i}$ or $\alpha_{c,i}$ of Equation 3.

[0086] The controller **120** may replace Equation 2, Equation 4, and Equation 5 for the modified Butler-Volmer's equation based on the concentration overvoltage of the

battery **110**. The modified Butler-Volmer's equation may be represented as shown in Equation 6.

$$j^{Li} = a_{s,i} i_{0,i} \left[\exp\left(\frac{\alpha_{a,i} F}{RT} \left(\varphi_s - \varphi_e - U_{i,ref} - \frac{j^{Li}}{a_{s,i}} - R_{f,i} - \eta_{conc,i} \right) \right) - \exp\left(-\frac{\alpha_{c,i} F}{RT} \left(\varphi_s - \varphi_e - U_{i,ref} - \frac{j^{Li}}{a_{s,i}} R_{f,i} - \eta_{conc,i} \right) \right) \right], \; i = n, \; p \tag{6}$$

[0087] In Equation 6, j^{Li} denotes a current density [A/m^3], $a_{s,i}$ denotes a specific surface area [1/m] representing a surface area over volume of an electrode active material, $i_{0,i}$ denotes an exchange current density [A/m^2], $\alpha_{a,i}$ denotes a charge transfer coefficient in the anode, F denotes a Faraday's constant [C/mol], R denotes a universal gas constant [J/(mol·K)], T denotes a temperature [K], φ_s denotes a solid potential [V], φ_e denotes an electrolyte potential [V], $U_{i,ref}$ denotes an equilibrium potential [V], $R_{f,i}$ denotes a film resistance [Ω·m^2], $\eta_{conc,i}$ denotes a concentration overvoltage [V], $\alpha_{c,i}$ denotes a charge transfer coefficient in the cathode, and i denotes a reaction in the anode (n) or a reaction in the cathode (p). That is, Equation 6 indicates the reaction in the anode or the reaction in the cathode depending on whether i is n or p.

[0088] The controller **120** calculates the current density j^{Li} from Equation 2, Equation 4, Equation 5, and Equation 6 using the Newton-Raphson method.

[0089] The controller **120** calculates the solid potential φ_s and the electrolyte potential φ_e using the charge conservation law.

[0090] The controller **120** calculates the surface concentration $c_{s,i}$ and the electrolyte concentration $c_{e,i}$ using the mass conservation law.

[0091] The controller **120** measures the battery state based on the current density j^{Li}, the solid potential α_s, the electrolyte potential α_e, the surface concentration $c_{s,i}$, and the electrolyte concentration $c_{e,i}$.

[0092] In a low temperature state, the battery **110** may operate in the same manner as in the high rate mode. The battery state measurement apparatus **100** may further include a second sensor **106**. The second sensor **106** measures a temperature of the battery **110**. The second sensor **106** outputs the measured temperature to the controller **120**.

[0093] When the temperature of the battery **110** is less than a third reference value, the controller **120** determines that the battery **110** is operating in the high rate mode. Here, regardless of whether the battery **110** actually operates in the high rate mode, an operation of the battery **110** may be the same as one in the high rate mode. The third reference value may be a value preset by the user. The user may set the third reference value based on the accuracy of the battery state measurement apparatus **100**.

[0094] Although FIG. **1** illustrates the battery **110** included in the battery state measurement apparatus **100**, this is provided as an example only. The battery **110** may be provided outside the battery state measurement apparatus **100**. That is, in an alternative example, the battery state measurement apparatus **100** may not include the battery **110**.

[0095] FIG. **2** illustrates an example of a configuration of a battery of FIG. **1**, FIG. **3**A illustrates an example of a low rate mode of a battery, FIG. **3**B illustrates an example of a graph showing a low rate mode of a battery, FIG. **4**A illustrates an example of a high rate mode of a battery, and FIG. **4**B illustrates an example of a graph showing a high rate mode of a battery.

[0096] Referring to FIG. **2** through FIG. **4**B, the battery **110** includes an anode, a cathode, and an electrolyte. The battery **110** supplies power to a load **200** through an electrochemical reaction.

[0097] In an example in which the battery **110** is configured as a lithium (Li) ion battery, a Li atom is separated into a Li ion (Li+) **101** and an electron e− through an oxidation reaction in the cathode of the battery **110**. The Li ion **101** may be transferred to the anode through a solvent molecule **102** of the electrolyte. The Li ion **101** may become the Li atom through a reduction reaction with the electron e− in the anode. For example, the Li ion **101** may cause the reduction reaction with the electron e− having transferred through a current collector **104** in an electrode active material **103**. That is, the battery **110** may output current through the oxidation reduction reaction.

[0098] FIGS. **3**A and **3**B show examples of a reaction of the battery **110** in a low rate mode. In the low rate mode, the Li ion **101** is transferred from the electrolyte through the solvent molecule **102**. Here, the Li ion **101** may experience a mass transfer resistance R_{mt} in the electrolyte. The Li ion **101** may experience a charge transfer resistance R_{ct} for causing the reduction reaction with the electron on a surface of the electrode active material **103**, that is, an interface between the electrolyte and the electrode. Also, the Li ion **101** may experience a diffusion resistance R_d with respect to transfer of the Li ion **101** within the active material.

[0099] Referring to FIG. **3**B, it is possible to verify reduction current or cathodic current i_c and oxidation current or anodic current i_a corresponding to a potential difference, that is, a difference between an electric potential φ and an equilibrium potential U_{eq}. The potential difference may be a value based on an activation overvoltage, for example, overpotential or an activation polarization (n_{ct}). An origin (U_{eq}) denotes the equilibrium potential or an open circuit potential (OCP). If the same charge transfer coefficient α is given, that is, $\alpha_{a,i}=\alpha_{c,i}$, the graph of FIG. **3**B is an origin symmetry. That is, the oxidation reaction and the reduction reaction in the battery **110** have opposite signs and have the same magnitude.

[0100] FIGS. **4**A and **4**B show examples of a reaction of the battery **110** in a high rate mode. In the high rate mode, the Li ion **101** is transferred from the electrolyte through the solvent molecule **102**. Here, the Li ion **101** may experience a mass transfer resistance R_{mt} and a charge transfer resistance R_{ct} in the electrolyte. The Li ion **101** may experience the charge transfer resistance R_{ct} for causing the reduction reaction with the electron on the surface of the electrode active material **103**, that is, the interface between the electrolyte and the electrode. Also, the Li ion **101** may experience a diffusion resistance R_d with respect to transfer of the Li ion **101** within the active material.

[0101] Referring to FIG. **4**B, it is possible to verify the reduction current i_c corresponding to the potential φ and the oxidation current i_a corresponding to the potential difference. The potential difference may be a value based on the activation overvoltage (η_{ct}) and the concentration overvoltage, for example, the concentration overpotential or the concentration polarization (η_c). The origin (U_{eq}) denotes the equilibrium potential. If the same charge transfer coefficient α is given, that is, if $\alpha_{a,i}=\alpha_{c,i}$, the graph of FIG. **4**B is an

origin symmetry. That is, the oxidation reaction and the reduction reaction in the battery **110** have opposite signs and have the same magnitude.

[0102] Compared to a case in which the battery **110** operates in the low rate mode, when the battery **110** operates in the high rate mode, the Li ion **101** experiences a relatively greater resistance. Thus, the concentration of the electrolyte may vary and the concentration overvoltage may occur. Accordingly, the controller **120** may measure the battery state of the battery **110** based on the concentration overvoltage.

[0103] Although FIGS. **3**A through **4**B are described by using the reduction reaction in the anode as an example for clarity of description, it is provided as an example only. The similar principle may be applied to the oxidation reaction.

[0104] FIG. **5** illustrates an example of a graph describing performance of a battery state measurement apparatus, and FIG. **6** illustrates an example of an enlarged partial section of the graph of FIG. **5**.

[0105] Referring to FIG. **5**, it is possible to compare a discharge characteristic curve (B-V and ConcOverpotential) measured by the battery state measurement apparatus **100** using a modified Butler-Volmer's equation based on concentration of the battery **110**, a discharge characteristic curve (B-V) measured using a comparative Butler-Volmer's equation, and an actual charging state (Ref.). Here, the battery **110** performs discharging in a high rate mode in which a rated capacity value is 60 Ah, an equilibrium potential is 4V, and a C-rate is 5C.

[0106] An enlarged area **510** of FIG. **5** is shown in FIG. **6**. That is, compared to the comparative example, the discharge voltage measured by the battery state measurement apparatus **100** shows a voltage drop of about 10 mV, which is relatively close to the actual charging state.

[0107] FIG. **7** illustrates a second example of a battery state measurement apparatus.

[0108] FIG. **7** illustrates a vehicle **700**. The vehicle **700** may be, for example, an electric vehicle, a hybrid vehicle, or a plug-in hybrid vehicle.

[0109] The battery state measurement apparatus **100** includes the battery **110** and the controller **120**.

[0110] The battery **110** includes one or more battery cells. For example, the battery **110** may indicate a battery cell, a battery module, or a battery pack.

[0111] When the battery **110** is configured as the battery pack or the battery module, the controller **120** may be understood as a BMS. That is, the controller **120** may include an M-BMS and one or more S-BMSs. The SBMSs may perform the same operation on a respective battery module or battery cell.

[0112] When the battery **110** is configured as the battery module, the S-BMS may collect physical quantity information of battery cells included in the battery **110**. The physical quantity information may include any one or any combination of, for example, voltage information, current information, temperature information, and impedance information. The S-BMS transmits the collected physical quantity information to the M-BMS. For example, the S-BMS transmits, to the M-BMS, the collected physical quantity information through a controller area network (CAN) communication, a wireless communication, and the like.

[0113] The M-BMS may determine a battery state of the battery cell, the battery module, and/or the battery pack based on the collected physical quantity information. The battery state may include, for example, an SOC or an SOH.

[0114] The M-BMS may receive a request for output information from a power management system, for example, an electronic control unit (ECU), within the vehicle **700**. The requested output information may include information, for example, a power command value, associated with power calculated by the power management system in response to a user starting an accelerator of the vehicle **700**. The M-BMS may determine outputtable power information of the battery pack based on state information, for example, an SOC and/or an SOH, of the battery pack.

[0115] The description made above with reference to FIGS. **1** through **6** may be applicable to the example of FIG. **7** and thus, a further description is omitted.

[0116] FIG. **8** is a flowchart illustrating an example of a battery state measurement method.

[0117] Referring to FIG. **8**, in operation **810**, the battery state measurement apparatus **100** determines an operational mode of the battery **110**. The operational mode of the battery **110** includes a high rate mode and a low rate mode. For example, the battery **110** may perform a general operation, such as charging, discharging, vehicle cruising, etc., in the low rate mode. The battery **110** may perform an operation, such as fast charging, fast discharging, sudden vehicle acceleration, etc., in a high rate mode.

[0118] The battery state measurement apparatus **100** determines the operational mode based on a current value output from the battery **110** or a voltage value of the battery **110**. The battery state measurement apparatus **100** calculates a C-rate based on the current value.

[0119] The battery state measurement apparatus **100** determines the operational mode based on the C-rate. For example, when the C-rate is greater than or equal to a first reference value, the battery state measurement apparatus **100** may determine that the battery **110** is operating in the high rate mode. When the C-rate is less than the first reference value, the battery state measurement apparatus **100** may determine that the battery **110** is operating in the low rate mode.

[0120] When the C-rate is less than the first reference value and the voltage value or a difference between a measured voltage value and an actual voltage value is greater than or equal to a second reference value, the battery state measurement apparatus **100** determines that the battery **110** is operating in the high rate mode. Here, each of the first reference value and the second reference value may be a value preset by the user based on accuracy of the battery state measurement apparatus **100**.

[0121] When the battery **110** operates in a low temperature, an operation of the battery **110** may be the same as one in the high rate mode. Accordingly, when a temperature of the battery **110** is less than a third reference value, the battery state measurement apparatus **100** determines that the battery **110** is operating in the high rate mode. Here, the third reference value may be a value preset by the user based on the accuracy of the battery state measurement apparatus **100**.

[0122] In operation **820**, the battery state measurement apparatus **100** measures the battery state using an electrochemical model in response to the battery **110** operating in the low rate mode. The electrochemical model includes a Butler-Volmer's equation. The battery state includes an SOC and/or an SOH.

[0123] In operation **830**, the battery state measurement apparatus **100** measures the battery state using a modified electrochemical model based on concentration of the battery **110** in response to the battery **110** operating in the high rate mode. The modified electrochemical model includes a modified Butler-Volmer's equation based on the concentration of the battery **110**.

[0124] The battery state measurement apparatus **100** described in FIGS. **1** and **7**, and other apparatuses, units, modules, devices, and other components described herein are implemented by hardware components configured to perform the operations described in this application that are performed by the hardware components. Examples of hardware components that may be used to perform the operations described in this application where appropriate include controllers, sensors, generators, drivers, memories, comparators, arithmetic logic units, adders, subtractors, multipliers, dividers, integrators, and any other electronic components configured to perform the operations described in this application. In other examples, one or more of the hardware components that perform the operations described in this application are implemented by computing hardware, for example, by one or more processors or computers. A processor or computer may be implemented by one or more processing elements, such as an array of logic gates, a controller and an arithmetic logic unit, a digital signal processor, a microcomputer, a programmable logic controller, a field-programmable gate array, a programmable logic array, a microprocessor, or any other device or combination of devices that is configured to respond to and execute instructions in a defined manner to achieve a desired result. In one example, a processor or computer includes, or is connected to, one or more memories storing instructions or software that are executed by the processor or computer. Hardware components implemented by a processor or computer may execute instructions or software, such as an operating system (OS) and one or more software applications that run on the OS, to perform the operations described in this application. The hardware components may also access, manipulate, process, create, and store data in response to execution of the instructions or software. For simplicity, the singular term "processor" or "computer" may be used in the description of the examples described in this application, but in other examples multiple processors or computers may be used, or a processor or computer may include multiple processing elements, or multiple types of processing elements, or both. For example, a single hardware component or two or more hardware components may be implemented by a single processor, or two or more processors, or a processor and a controller. One or more hardware components may be implemented by one or more processors, or a processor and a controller, and one or more other hardware components may be implemented by one or more other processors, or another processor and another controller. One or more processors, or a processor and a controller, may implement a single hardware component, or two or more hardware components. A hardware component may have any one or more of different processing configurations, examples of which include a single processor, independent processors, parallel processors, single-instruction single-data (SISD) multiprocessing, single-instruction multiple-data (SIMD) multiprocessing, multiple-instruction single-data (MISD) multiprocessing, and multiple-instruction multiple-data (MIMD) multiprocessing.

[0125] The methods illustrated in FIGS. **2-6** and **8** that perform the operations described in this application are performed by computing hardware, for example, by one or more processors or computers, implemented as described above executing instructions or software to perform the operations described in this application that are performed by the methods. For example, a single operation or two or more operations may be performed by a single processor, or two or more processors, or a processor and a controller. One or more operations may be performed by one or more processors, or a processor and a controller, and one or more other operations may be performed by one or more other processors, or another processor and another controller. One or more processors, or a processor and a controller, may perform a single operation, or two or more operations.

[0126] Instructions or software to control a processor or computer to implement the hardware components and perform the methods as described above are written as computer programs, code segments, instructions or any combination thereof, for individually or collectively instructing or configuring the processor or computer to operate as a machine or special-purpose computer to perform the operations performed by the hardware components and the methods as described above. In one example, the instructions or software include machine code that is directly executed by the processor or computer, such as machine code produced by a compiler. In another example, the instructions or software include higher-level code that is executed by the processor or computer using an interpreter. Programmers of ordinary skill in the art can readily write the instructions or software based on the block diagrams and the flow charts illustrated in the drawings and the corresponding descriptions in the specification, which disclose algorithms for performing the operations performed by the hardware components and the methods as described above.

[0127] The instructions or software to control a processor or computer to implement the hardware components and perform the methods as described above, and any associated data, data files, and data structures, are recorded, stored, or fixed in or on one or more non-transitory computer-readable storage media. Examples of a non-transitory computer-readable storage medium include read-only memory (ROM), random-access programmable read only memory (PROM), electrically erasable programmable read-only memory (EEPROM), random-access memory (RAM), dynamic random access memory (DRAM), static random access memory (SRAM), flash memory, non-volatile memory, CD-ROMs, CD-Rs, CD+Rs, CD-RWs, CD+RWs, DVD-ROMs, DVD-Rs, DVD+Rs, DVD-RWs, DVD+RWs, DVD-RAMs, BD-ROMs, BD-Rs, BD-R LTHs, BD-REs, blue-ray or optical disk storage, hard disk drive (HDD), solid state drive (SSD), flash memory, a card type memory such as multimedia card micro or a card (for example, secure digital (SD) or extreme digital (XD)), magnetic tapes, floppy disks, magneto-optical data storage devices, optical data storage devices, hard disks, solid-state disks, and any other device that is configured to store the instructions or software and any associated data, data files, and data structures in a non-transitory manner and providing the instructions or software and any associated data, data files, and data structures to a processor or computer so that the processor or computer can execute the instructions.

[0128] While this disclosure includes specific examples, it will be apparent after an understanding of the disclosure of

this application that various changes in form and details may be made in these examples without departing from the spirit and scope of the claims and their equivalents. The examples described herein are to be considered in a descriptive sense only, and not for purposes of limitation. Descriptions of features or aspects in each example are to be considered as being applicable to similar features or aspects in other examples. Suitable results may be achieved if the described techniques are performed in a different order, and/or if components in a described system, architecture, device, or circuit are combined in a different manner, and/or replaced or supplemented by other components or their equivalents. Therefore, the scope of the disclosure is defined not by the detailed description, but by the claims and their equivalents, and all variations within the scope of the claims and their equivalents are to be construed as being included in the disclosure.

What is claimed is:

1. A method of measuring a battery state of a battery, comprising:

determining an operational mode of a battery;

measuring a battery state using electrochemical equations based on an activation overvoltage in response to the battery operating in a low rate mode; and

measuring the battery state using modified electrochemical equations based on a concentration overvoltage and the activation overvoltage in response to the battery operating in a high rate mode.

2. The method of claim **1**, measuring the battery state using modified electrochemical equations comprises calculating internal potential information of the battery using the charge conservation law.

3. The method of claim **1**, measuring the battery state using modified electrochemical equations comprises calculating internal concentration information concentration using the mass conservation law.

4. The method of claim **1**, wherein the modified electrochemical equations comprise, modified Butler-Volmer's equation based on the concentration overvoltage.

5. The method of claim **1**, the determining comprises:

calculating a current rate (C-rate) based on a current value output from the battery; and

determining the operational mode based on the C-rate.

6. The method of claim **5**, wherein the determining of the operational mode based on the C-rate comprises:

calculating the C-rate based on a current value output from the battery

determining that the battery is operating in the high rate mode in response to the C-rate being greater than or equal to a first preset reference value; and

determining that the battery is operating in the low rate mode in response to the C-rate being less than the first preset reference value.

7. The method of claim **5**, wherein the determining of the operational mode based on the C-rate further comprises:

acquiring a voltage value of the battery; and

determining that the battery is operating in the high rate mode in response to the C-rate being less than the first preset reference value and the voltage value being greater than or equal to a second preset reference value.

8. The method of claim **1**, wherein the determining further comprises

measuring a temperature of the battery; and

determining that the battery is operating in the high rate mode in response to the temperature being less than a third preset reference value

9. An apparatus for measuring a battery state, the apparatus comprising:

a battery; and

a controller configured to

determine an operational mode of a battery;

measure a battery state using electrochemical equations based on an activation overvoltage in response to the battery operating in a low rate mode; and

measure the battery state using modified electrochemical equations based on a concentration overvoltage and the activation overvoltage in response to the battery operating in a high rate mode

10. The apparatus of claim **9**, wherein the controller is configured to calculate internal potential information of the battery using the charge conservation law.

11. The apparatus of claim **9**, wherein the controller is configured to calculate internal concentration information concentration using the mass conservation law.

12. The apparatus of claim **9**, wherein the modified electrochemical equations comprise, modified Butler-Volmer's equation based on the concentration overvoltage.

13. The apparatus of claim **9**, further comprising:

a first sensor configured to measure a current value output from the battery,

wherein the controller is configured to calculate a current rate (C-rate) based on the current value, and to determine the operational mode based on the C-rate

14. The apparatus of claim **13**, wherein the controller is configured to determine that the battery is operating in the high rate mode in response to the C-rate being greater than or equal to a first preset reference value, and to determine that the battery is operating in the low rate mode in response to the C-rate being less than the first preset reference value.

15. The apparatus of claim **13**, wherein the first sensor is configured to acquire a voltage value of the battery, and

the controller is configured to determine that the battery is operating in the high rate mode in response to the C-rate being less than the first preset reference value and the voltage value being greater than or equal to a second preset reference value.

16. The apparatus of claim **9**, further comprising:

a second sensor configured to measure a temperature of the battery,

wherein the controller is configured to determine that the battery is operating in the high rate mode in response to the temperature being less than a third preset reference value.

* * * * *