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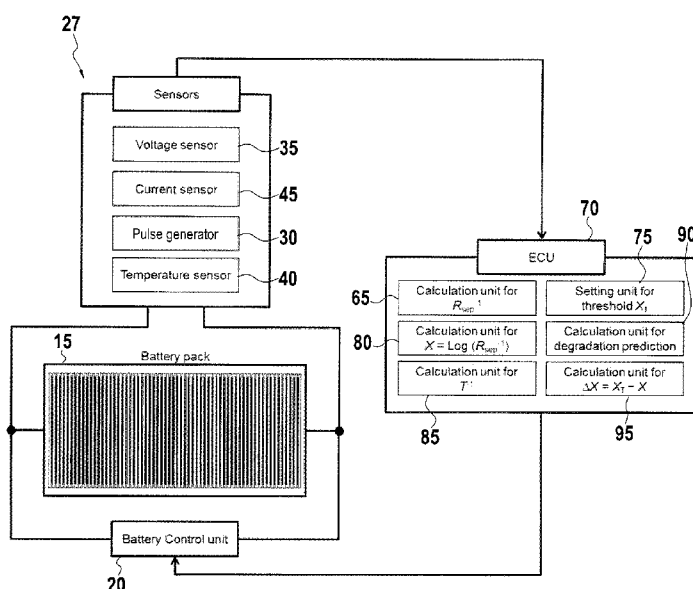


FIG.1

(57) Abstract: A system for determining a battery condition is provided. The system includes pulse generating means configured to supply a pulse at one or more predetermined current values, voltage sensing means configured to measure a voltage across the battery, and a controller. The controller is configured to determine a present impedance associated with one or more separator membranes of the battery based on a determined voltage drop at the one or more predetermined current values, determine a threshold impedance associated with the one or more separator membranes of the battery based on an initial impedance of the separator membrane and a battery temperature frequency, compare, during operation of the battery, the present impedance and the threshold impedance, permit current flow to and from the battery when the present impedance is greater than the threshold impedance, and prevent current flow to and from the battery when the present impedance is less than or equal to the threshold impedance.

SYSTEMS AND METHODS FOR BATTERY MICRO-SHORT ESTIMATION

Field of the Disclosure

5 [001] The present disclosure is related to systems and methods for determination of whether to allow operation of, i.e., current flow to and from, a battery. More particularly, the present disclosure is related to determination of a micro-short circuit in a battery that may require stopping of battery operation.

Background of the Disclosure

10 [002] Rechargeable batteries, also called secondary cells, have become increasingly important as energy stores, in particular for vehicles. Such vehicles may be hybrid vehicles comprising an internal combustion engine and one or more electric motors or purely electrically driven vehicles.

15 [003] A suitable rechargeable battery for such a vehicle may be a solid-state bipolar battery or other, e.g. liquid type batteries, in particular a laminated Li-ion battery. The rechargeable battery may be realized by a single cell or it may include a set of identical cells. In the latter case the battery is also called a battery pack.

20 [004] A relevant characteristic of a battery is its capacity. A battery's capacity is the amount of electric charge it can deliver at a rated voltage. The more electrode material contained in the battery the greater is its capacity. The capacity is measured in units such as amp-hour (A·h).

25 [005] The battery or the battery pack may include a control device for controlling charging and/or discharging. The control device monitors state of charge (SOC) of the battery and generally allows the battery to operate within its safe operating area. Such a battery or battery pack is also called a smart battery / smart battery pack. It is also possible that the control device is provided by the vehicle.

30 [006] One important aspect of charge and discharge control is to assure that any overcharging and/or over-discharging of the battery is

avoided. For this purpose the battery voltage may be monitored, which is increasing during charging and decreasing during discharging.

[007] However, during the lifetime of a battery the charging and discharging procedures may lead to a degradation of the laminated layers of the battery. In particular a separator membrane present within the electrolyte between the anode and the cathode of the battery. The degradation can lead to internal micro-short circuits of battery, which in turn increases the risk of problems with the battery during operation (e.g., thermal runaway).

[008] US 2001/0028238 discloses that the internal impedance related value which is related to the internal impedance of a secondary battery is compared with a previously obtained relation between the internal impedance related value and battery condition to judge the battery condition of the secondary battery. Since the internal impedance related value is a value related to the internal impedance which closely depends on the battery condition, the battery condition can be judged in detail based on such a relation.

[009] However, in the above technology a semi-circular portion of a Nyquist plot are utilized, this portion including many additional factors of impedance that may not be related to micro-short circuits present in the separator membrane. Therefore, state of charge (SOC), type of deterioration of the battery, and temperature have an impact on the values and the technique of US 2001/0028238 may not yield results with a desired amount of accuracy.

SUMMARY OF THE INVENTION

[010] The inventors of the present invention desire to enable more accurate detection of micro-shorts resulting from degradation of a separation membrane within a battery pack while simplifying structure and procedure.

[011] Therefore, according to embodiments of the present disclosure, a system for determining a battery condition is provided. The system

may include pulse generating means configured to supply a pulse at one or more predetermined current values, voltage sensing means configured to measure a voltage across the battery, and a controller.

5 The controller may be configured to determine a present impedance associated with one or more separator membranes of the battery based on a determined voltage drop at the one or more predetermined current values, determine a threshold impedance associated with the one or more separator membranes of the battery based on an initial impedance of the separator membrane and a battery temperature frequency,
10 compare, during operation of the battery, the present impedance and the threshold impedance, permit current flow to and from the battery when the present impedance is greater than the threshold impedance, and prevent current flow to and from the battery when the present impedance is less than or equal to the threshold impedance.

15 [012] By providing a system according to the present disclosure, the inventors have made it possible to more accurately detect a micro-short circuit in a battery and stop operation of the battery to prevent conditions undesirable for battery operation. This may in turn improve battery safety and battery life.

20 [013] The pulse generating means may be configured to generate multiple pulses at predetermined intervals and at increasing current values.

[014] The pulse at one or more predetermined current values may be supplied during a pause in battery operation.

25 [015] The initial impedance may be measured in advance over a range of temperatures for a given equilibrium constant, and the measured values stored in a data map.

[016] The threshold impedance may be further determined based on the values stored in the data map.

30 [017] The controller may be configured to account for degradation of the battery based at least on the temperature frequency of the battery.

[018] The threshold impedance may be reduced based on a degradation coefficient.

[019] The degradation coefficient may be determined in advance by measuring degradation of an exemplary battery under exemplary use conditions, and at a plurality of temperature frequency values, the measured degradation being correlated to temperature frequency in a data map.

[020] The battery may include at least one of a lithium-ion solid-state battery and a lithium-ion liquid electrolyte battery.

[021] According to further embodiments, a vehicle comprising the system described above is provided.

[022] According to still further embodiments, a method for controlling a battery is provided. The method includes determining a battery temperature frequency, applying one or more current pulses to the battery at one or more predetermined current values, determining a present impedance associated with one or more separator membranes of the battery based on a determined voltage drop at the one or more predetermined current values, determining a threshold impedance associated with the one or more separator membranes of the battery based on an initial impedance of the separator membrane and the battery temperature frequency, comparing a present impedance associated with the one or more separator membranes of the battery, and permitting current flow to and from the battery when actual impedance is greater than the threshold impedance, preventing current flow to and from the battery when the actual impedance is less than or equal to the threshold impedance.

[023] By providing a method according to the present disclosure, the inventors have made it possible to more accurately detect a micro-short circuit in a battery and stop operation of the battery to prevent conditions undesirable for battery operation. This may in turn improve battery safety and battery life.

[024] The applying may include generating multiple pulses at predetermined intervals and at increasing current values.

[025] The applying may take place during a pause in battery operation.

5 [026] The method may further include measuring the initial impedance in advance over a range of temperatures for a given equilibrium constant, and storing the measured values in a data map.

[027] The threshold impedance may further be determined based on the values stored in the data map.

10 [028] The method may further include accounting for degradation of the battery based at least on a temperature frequency of the battery.

[029] The threshold impedance may be reduced based on a degradation coefficient.

15 [030] The degradation coefficient may be determined in advance by measuring degradation of an exemplary battery under exemplary use conditions, and at a plurality of temperature frequency values, the measured degradation being correlated to temperature frequency in a data map.

20 [031] The battery may be at least one of a lithium-ion solid-state battery and a lithium-ion liquid electrolyte battery.

[032] Additional objects and advantages of the invention will be set forth in part in the description which follows, or may be learned by practice of the invention. The objects and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

25 [033] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

30 [034] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

- [035] Fig. 1 is a schematic diagram of a system for monitoring a battery condition according to embodiments of the present disclosure;
- 5 [036] Fig. 2 is a flowchart showing one exemplary method for condition monitoring according to embodiments of the present disclosure;
- [037] Fig. 3A is a chart showing an exemplary pulsed current application to a battery;
- [038] Fig. 3B is a graph showing an exemplary voltage response of a battery to the pulsed current application of Fig. 3A;
- 10 [039] Fig. 3C is a plot of the voltage response of Fig. 3B to the pulsed current of 3A, the slope of which represents an impedance estimation of a battery separator;
- [040] Fig. 3D is a graph showing an impedance region in which a battery is permitted to operate and a shaded impedance region in which operation of the battery should be prevented;
- 15 [041] Fig. 4 is a flowchart showing one exemplary method for battery degradation compensation;
- [042] Fig. 5 is a graph representing an initial impedance of a battery and determination of a degradation compensated threshold impedance;
- 20 [043] Fig. 6 shows an exemplary and schematic diagram of a determined temperature / frequency distribution of a battery; and
- [044] Fig. 7 shows an exemplary and schematic diagram of a predetermined degradation rate in relation to the temperature of a battery.
- 25

DESCRIPTION OF THE EMBODIMENTS

- [045] Reference will now be made in detail to the present exemplary
- 30 embodiments of the disclosure, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[046] Fig. 1 is a schematic diagram of a system for monitoring a battery condition according to embodiments of the present disclosure. The system may include a battery pack 15, one or more sensors 27, ECU 70, and a charging control unit 20. Battery pack 15 may include one or more battery cells 10, and a dummy cell (not shown), among others. Battery pack 15 may be any suitable type of battery, for example, a lithium ion battery, a NiMH battery, lead acid battery, etc.

[047] Battery controller 20 may comprise any suitable battery controller configured to control operational processes of battery pack 15, e.g., charging the battery cells 10, discharging battery cells 10, etc.

[048] As one of skill in the art understands, lithium ion batteries in particular involve relatively strict charging and discharging circumstances to be maintained during a battery charging and discharging in order to avoid dangerous conditions such as overheating and overcharging.

Therefore, battery controller 20 may be configured to control current and voltage flowing to and from battery pack 15 during charging and discharging, among others. For example, when it is determined that a micro-short has occurred, battery controller 20 may prevent battery pack 15 from operating.

[049] Battery pack 15 may be connected to an inverter (not shown) which may in turn be connected to one or more motors, to permit energy stored in battery pack 15 during a charging process to be stepped up by the inverter and fed to the motor during a discharging process, thereby resulting in movement of the vehicle.

[050] Each battery cell 10 may include an anode, a cathode, an electrolyte, and a separator membrane in the electrolyte separating the anode and cathode, among others. Battery cells 10 may be stacked (e.g., in a bi-polar fashion) within a housing associated with battery pack 15 to form battery pack 15. For example, battery pack 15 may include a housing configured to have one or more battery cells 10 stacked and connected therein.

[051] Each battery cell 10 present in battery pack 15 may be connected in series or in parallel to other battery cells 10 present in

battery pack 15. One of skill in the art will recognize that various criteria such as a desired voltage, a desired maximum current, etc. may be considered when designing a battery and connections as described herein.

5 [052] Battery pack 15 may include one or more dummy cells (not shown) conductively linked to battery cells 10 to permit measurement of an open circuit voltage V_{ocv} across the totality of battery cells 10 present within battery pack 15 by voltage sensor 35. For example, a dummy cell configured to provide a dummy load may be connected in parallel with
10 each of battery cells 10 present within battery pack 15, and the output (i.e., open circuit voltage) may be provided to sensor bank 27, and more particularly voltage sensor 35. One of skill in the art will recognize that more than one dummy cell- may be provided, for example one dummy cell for each battery cell 10 present in battery pack 15.

15 [053] A number of sensors 27 and/or pulse generators may be provided with battery pack 15, including, for example, voltage sensor 35, a current sensor 45 configured to obtain current flow information to and from battery pack 15, temperature sensor 40 configured to sense a temperature of battery pack 15, a pulse generator 30 configured to
20 provide a current pulse and/or a voltage pulse to battery pack 15, etc.

[054] One or more of these sensors 27 be located within the battery pack itself and/or directly linked to elements of battery pack 15 enabling respective measurements to be taken from battery pack 15.

[055] Sensors associated with battery pack 15 may be configured to
25 provide signals to sensor bank 27, thereby enabling sensor bank 27 to monitor information associated with battery pack 15 (e.g. open circuit voltage V_{ocv} , impedance spectrum, temperature, etc.) during operation of the battery, i.e., a charging and/or discharging process and to provide the information to battery ECU 70, among others.

30 [056] Pulse generator 30 may be configured to provide current pulses at varying current values. According to some embodiments, pulse generator 30 may be configured to apply a current pulse during a pause in battery operation (i.e., while no current other than that of the pulse

flows into or out of the battery pack 15). This may aid in obtaining more accurate results, among others.

[057] For example, as shown at Fig. 3A, a plurality of current pulses of increasing current value may be applied over time to enable measurement of a voltage drop V_{drop} across battery pack 15, thereby permitting determination of separator impedance within battery cells 10 as described below.

[058] Particularly, because it can be assumed that the separator impedance obeys the Ohmic law $V_{\text{drop}} = I * R_{\text{sep}}$, application of a known current, while measuring a voltage drop permits determination of separator impedance R_{sep} . Based on the above, to obtain a more accurate value of R_{sep} , an I - V_{drop} curve may be created based on measured values of V_{drop} at various currents I_x , as shown at Fig. 3C. An average separator impedance R_{sep} may then be calculated as the slope of the resulting I - V_{drop} line.

[059] When a current I_x is applied to battery pack 15, voltage $V_{\text{drop_total}}$ changes over time t . $V_{\text{drop_total}}$ can be broken into two components, an initial voltage drop $V_{\text{drop_initial}}$ which is current dependent, but time independent, and reactive voltage drop $V_{\text{drop_reactive}}$ which is both current and time dependent. Therefore, using the discharge curve of a battery pack 15, an example of which is shown at Fig. 3B, V_{drop} can be determined based on an initial voltage V_{initial} and a voltage at the inflection point of the curve V_{inf} as shown at equation 1.

$$V_{\text{drop_total}} = V_{\text{initial}} - V_{\text{inf}} \quad \dots(1)$$

[060] Alternatively, or in addition, V_{drop} may be determined by taking the initial voltage V_{initial} and a voltage at a predetermined time, such time being as small as possible (e.g., $0.005\text{s} < t < 0.5\text{s}$, better $0.01\text{s} < t < 0.1\text{s}$) as shown by equation 2.

$$V_{\text{drop_total}} = V_{\text{initial}} - V_t \quad \dots(2)$$

[061] According to some embodiments, a state of charge detector may also be provided and may be configured to receive current information from current sensor 45 as well as voltage information from

voltage sensor 35 in order to determine a state of charge (SOC) of battery pack 15.

[062] However, by using the voltage drop, as described above, it becomes possible to avoid the time lag encountered based on the effects of using state of charge (SOC).

[063] Values from sensor bank 27 may be provided to battery ECU 70, with battery ECU 70 providing command signals battery controller 20 (e.g. operational control commands). For example battery ECU 70 may include a impedance calculation unit 65 for determining a reciprocal of a impedance (R_{sep}^{-1}) of one or more separator membranes associated with battery cells 10, a threshold setting unit 75 for setting a threshold impedance X_T , a degradation prediction unit 90 for estimating an amount of degradation of each battery cell 10, a temperature corrected impedance calculation unit 80 for calculating temperature and degradation corrected impedance value of the separators, a reciprocal temperature calculation unit 85, and a difference determination unit 95 for determining whether a corrected impedance falls within an operational region of the battery 15 (i.e., whether a micro-short in one or more separator membranes has occurred).

[064] Battery ECU 70 may include a memory configured to store values obtained from sensor bank 27, among others. For example, battery ECU 70 may store voltage values obtained from voltage sensor 35, temperature values obtained from temperature detector 40, current output data received from pulse generator 30, current flow data received from current sensor 45, etc., as well as map values associated with data experimentally obtained from an exemplary battery design corresponding to the battery pack 15 installed in the vehicle (e.g. degradation rate information, initial resistance/impedance values of separator membranes, etc.)

[065] A history of values may be compiled and stored over the life of the battery pack 15 during use of the vehicle, and according to some embodiments, when the vehicle is stored (i.e., not being driven). By compiling such data it may be possible to determine the history of

temperatures, voltages, current flows, etc. to which battery pack 15 has been subjected, as well as an amount of time over which the battery was subject to each of said values. Such a history may be used to augment processes described below for determining certain values, for example, temperature frequency.

[066] One of skill in the art will understand that the memory associated with battery ECU 70 may be comprised within battery ECU 70, or may be present on and or in other systems of the vehicle providing communication access to battery ECU 70, for example, within the battery pack 15 itself.

[067] Once a battery pack 15 has been assembled and closed, for example, with a cover over the housing, an initial impedance $R_{sep_initial}$ associated with the separator membranes of the battery pack 15 may be measured over a plurality of temperatures (e.g., -40C to 60C), and these impedance values stored in the memory associated with battery ECU 70. For example, these impedance values may be used to create a lookup data map that may be accessed during processing by ECU 70. Such a data map may be used throughout the life of battery pack 15 as a comparison to a current impedance of separator membranes, as described below.

[068] Fig. 2 is a flowchart 200 showing an exemplary method for micro-short estimation according to embodiments of the present disclosure. At regular intervals (e.g., every 10 ms), battery ECU may obtain a temperature of battery pack 15 as determined by temperature detector 40 based on information provided by a temperature sensor present in battery pack 15 (step 205). These temperature values may then be stored in the memory associated with ECU 70.

[069] One or more current pulses may then be applied to battery pack 15 by pulse generator 30, voltage drop V_{drop_total} calculated, and separator impedance R_{sep} determined, as described above (step 210).

[070] Regardless of the determination method for separator impedance R_{sep} , impedance calculation unit 65 may then calculate a

reciprocal of separator impedance R_{sep} , i.e., R_{sep}^{-1} , and provide this value to temperature corrected impedance calculation unit 80.

[071] Similarly, reciprocal temperature calculation unit 85 may receive current temperature T of battery pack 15 from temperature sensor 40 and calculate a reciprocal of this temperature (i.e., T^{-1}) for providing to temperature corrected impedance calculation unit 80.

[072] Because R_{sep} depends on temperature, a temperature corrected impedance value X is calculated according to the Arrhenius equation shown here at equation 3 (step 215).

$$X = \log(R_{sep}^{-1}) \propto T^{-1} \quad \dots(3)$$

[073] Following calculation of the temperature corrected impedance value X , a threshold impedance value X_T is calculated by threshold setting unit 75. Because there is a possibility of degradation of the battery 15, a degradation rate (i.e., a degradation coefficient) should be considered when preparing the threshold impedance value X_T in order to provide more accurate results. Such a degradation rate depends on a calculated temperature frequency T_x to which the battery pack 15 has been subjected over its lifetime. As noted above, because a temperature history of battery pack 15 may be stored in a memory associated with ECU 70, such a temperature frequency may be determined.

[074] Fig. 4 is a flowchart showing one exemplary method for battery degradation compensation for use when determining a threshold separator impedance X_T . According to embodiments of the disclosure, a temperature frequency to which the battery pack 15 has been exposed over its lifetime is calculated (step 405).

[075] Fig. 6 shows an exemplary schematic diagram of a determined temperature / frequency distribution of a battery cell. In the diagram the x-axis represents the temperature T of the battery cell 10 and the y-axis represents a frequency, i.e., the inverse of time t . In other words, Fig. 6 contains the accumulated temperature data of the battery pack 15 over its entire life time, i.e. over the whole time battery pack 15 has been in

use and the storage times between the usage, this data being stored, for example, in the memory by battery ECU 70.

[076] In order to establish the data for a battery pack 15, i.e.

corresponding to the illustrated curve, it is determined for each

5 temperature to which battery pack 15 was exposed during its life time, e.g. from -40°C to + 60°C in (quantized) steps of 1°C, how much time the battery pack 15 spent at such temperature. The accumulated time in the chart is thereby expressed by its inverse, i.e. by a frequency. One of skill in the art will recognize that the temperature of each battery pack 15 should approximately correspond to that each battery cell 10, so that their degradation is the approximately identical.

[077] Importantly, a degradation rate β depends on the temperature frequency T_x and is predetermined and specific for the type of the battery cells 10 comprising battery pack 15, which preferably corresponds to the type of the battery pack 15 (e.g., solid state lithium ion). The degradation rate β is preferably determined in pre-experiment and is stored by the battery (in case of a smart battery) and/or by the battery ECU 70. An exemplary data map is shown at Fig. 7.

[078] A method for plotting the map of Fig. 7 is discussed below.

20 [079] Prior to placing a battery in service, an initial separator impedance $R_{sep_initial}$ of an exemplary battery may be measured and the value stored.

[080] The exemplary battery may then be placed in a temperature controlled chamber and subjected to varying temperatures over varying time periods. The temperature frequency can then be calculated by equation 4.

$$T_x = \frac{1}{t} \int_t^1 T(t) dt \quad \dots(4)$$

[081] The impedance of the exemplary battery may then be measured following the exposure to the varying temperatures, and a temperature adjusted impedance $R_{sep}(T_x)$ determined and the value stored.

30

[082] The degradation rate can then be calculated at a given temperature frequency T_x based on equation 5.

$$\beta = R(T_x) / R_{\text{initial}} \quad \dots(5)$$

[083] The data map shown at Fig. 7 can then be created plotting Plot the $(1000/T_x, \beta)$ on the graph of $1000/T_x$ vs $\ln(\beta)$.

[084] Once the temperature frequency of the battery has been mapped, a degradation rate β for a particular temperature frequency can be determined based on the data map as shown at Fig. 7 (step 410).

[085] Once a degradation rate β has been determined for a particular temperature frequency T_x associated with the in-service battery pack 15, an initial corrected impedance X_{initial} may be loaded from a data map, as described below.

[086] Fig. 5 is a graph representing an initial impedance X_{initial} of a battery and determination of a degradation compensated threshold impedance X_T . As noted above, an initial impedance $R_{\text{sep_initial}}$ for a new exemplary battery is measured over a range of temperatures and a data map correlating initial impedance $R_{\text{sep_initial}}$ to an initial resistance value X_{initial} is created using equation 6 to account for the correlation to temperature (i.e., Arrhenius law).

$$X_{\text{initial}} = \log(R_{\text{sep_initial}}^{-1}) \quad \dots(6)$$

[087] In order to determine the relevant point on the initial impedance map, it is possible to load, from the data map, an initial corrected impedance X_{initial} (step 415).

[088] Once the initial corrected impedance X_{initial} has been determined, the threshold impedance X_T may be determined using equation 7 (step 420).

$$X_T = \log\{(\beta * R_{\text{sep_initial}})^{-1}\} \quad \dots(7)$$

[089] As shown at Fig. 5 (and Fig. 3D), using this equation produces an operating region 320 in which a battery pack 15 is permitted to operate by battery controller 20, and a micro-short region 310, in which battery controller 20 is configured to prevent operation of battery pack 15.

[090] By calculating a impedance delta ΔX according to equation 8 (step 230), it then becomes possible to evaluate whether the impedance delta ΔX is less than 0 (i.e., in the micro-short region 310) (step 240: yes) so that battery operation may be stopped (step 250) and an alert sent (step 260). Notably, stopping of operation may include preventing current flow to and from battery pack 15, while an alert may comprise a sound, a visual effect, or any other suitable warning to an operator of a vehicle that battery pack 15 may be failing or inoperable.

$$\Delta X = X_T - X \quad \dots(8)$$

[091] When the impedance delta ΔX is greater than or equal to 0 (step 240: no) battery controller may allow battery pack 15 to continue to operate, i.e., current to flow to and from battery pack 15.

[092] Throughout the description, including the claims, the term "comprising a" should be understood as being synonymous with "comprising at least one" unless otherwise stated. In addition, any range set forth in the description, including the claims should be understood as including its end value(s) unless otherwise stated. Specific values for described elements should be understood to be within accepted manufacturing or industry tolerances known to one of skill in the art, and any use of the terms "substantially" and/or "approximately" and/or "generally" should be understood to mean falling within such accepted tolerances.

[093] Where any standards of national, international, or other standards body are referenced (e.g., ISO, etc.), such references are intended to refer to the standard as defined by the national or international standards body as of the priority date of the present specification. Any subsequent substantive changes to such standards are not intended to modify the scope and/or definitions of the present disclosure and/or claims.

[094] It is intended that the specification and examples be considered as exemplary only, with a true scope of the disclosure being indicated by the following claims.

CLAIMS

1. A system for determining a battery condition, comprising:
pulse generating means configured to supply a pulse at one or more
5 predetermined current values;
voltage sensing means configured to measure a voltage across the
battery; and
a controller configured to:
determine a present impedance associated with one or more
10 separator membranes of the battery based on a determined voltage drop at
the one or more predetermined current values;
determine a threshold impedance associated with the one or more
separator membranes of the battery based on an initial impedance of the
separator membrane and a battery temperature frequency;
15 compare, during operation of the battery, the present impedance
and the threshold impedance;
permit current flow to and from the battery when the present
impedance is greater than the threshold impedance; and
prevent current flow to and from the battery when the present
20 impedance is less than or equal to the threshold impedance.
2. The system according to claim 1, wherein the pulse generating
means is configured to generate multiple pulses at predetermined intervals
and at increasing current values.
- 25 3. The system according to any of claims 1-2, wherein the pulse at one
or more predetermined current values is supplied during a pause in battery
operation.
- 30 4. The system according to any of claims 1-3, wherein the initial
impedance is measured in advance over a range of temperatures for a given
equilibrium constant, and the measured values stored in a data map.
- 35 5. The system according to claim 4, wherein the threshold impedance
is further determined based on the values stored in the data map.

6. The system according to claim 5, wherein the controller is configured to account for degradation of the battery based at least on the temperature frequency of the battery.

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7. The system according to claim 6, wherein the threshold impedance is reduced based on a degradation coefficient.

8. The system according to claim 7, wherein the degradation coefficient is determined in advance by measuring degradation of an exemplary battery under exemplary use conditions, and at a plurality of temperature frequency values, the measured degradation being correlated to temperature frequency in a data map.

9. The system according to any of claims 1-8, wherein the battery comprises at least one of a lithium-ion solid-state battery and a lithium-ion liquid electrolyte battery.

10. A vehicle comprising the system according to any of claims 1-9.

20

11. A method for controlling a battery, comprising:

determining a battery temperature frequency;

applying one or more current pulses to the battery at one or more predetermined current values;

25 determining a present impedance associated with one or more separator membranes of the battery based on a determined voltage drop at the one or more predetermined current values;

determining a threshold impedance associated with the one or more separator membranes of the battery based on an initial impedance of the separator membrane and the battery temperature frequency;

30

comparing a present impedance associated with the one or more separator membranes of the battery; and

permitting current flow to and from the battery when actual impedance is greater than the threshold impedance;

preventing current flow to and from the battery when the actual impedance is less than or equal to the threshold impedance.

12. The method according to claim 11, wherein the applying includes
5 generating multiple pulses at predetermined intervals and at increasing current values.

13. The method according to any of claims 11-12, wherein the applying
10 takes place during a pause in battery operation.

14. The method according to any of claims 10-13, further comprising
measuring the initial impedance in advance over a range of temperatures for
a given equilibrium constant, and storing the measured values in a data map.

15. The method according to claim 14, wherein the threshold impedance
15 is further determined based on the values stored in the data map.

16. The method according to claim 15, comprising accounting for
degradation of the battery based at least on a temperature frequency of the
20 battery.

17. The method according to claim 16, wherein the threshold impedance
is reduced based on a degradation coefficient.

18. The method according to claim 17, wherein the degradation
25 coefficient is determined in advance by measuring degradation of an exemplary battery under exemplary use conditions, and at a plurality of temperature frequency values, the measured degradation being correlated to temperature frequency in a data map.

19. The method control system according to any of claims 11-18,
30 wherein the battery comprises at least one of a lithium-ion solid-state battery and a lithium-ion liquid electrolyte battery.

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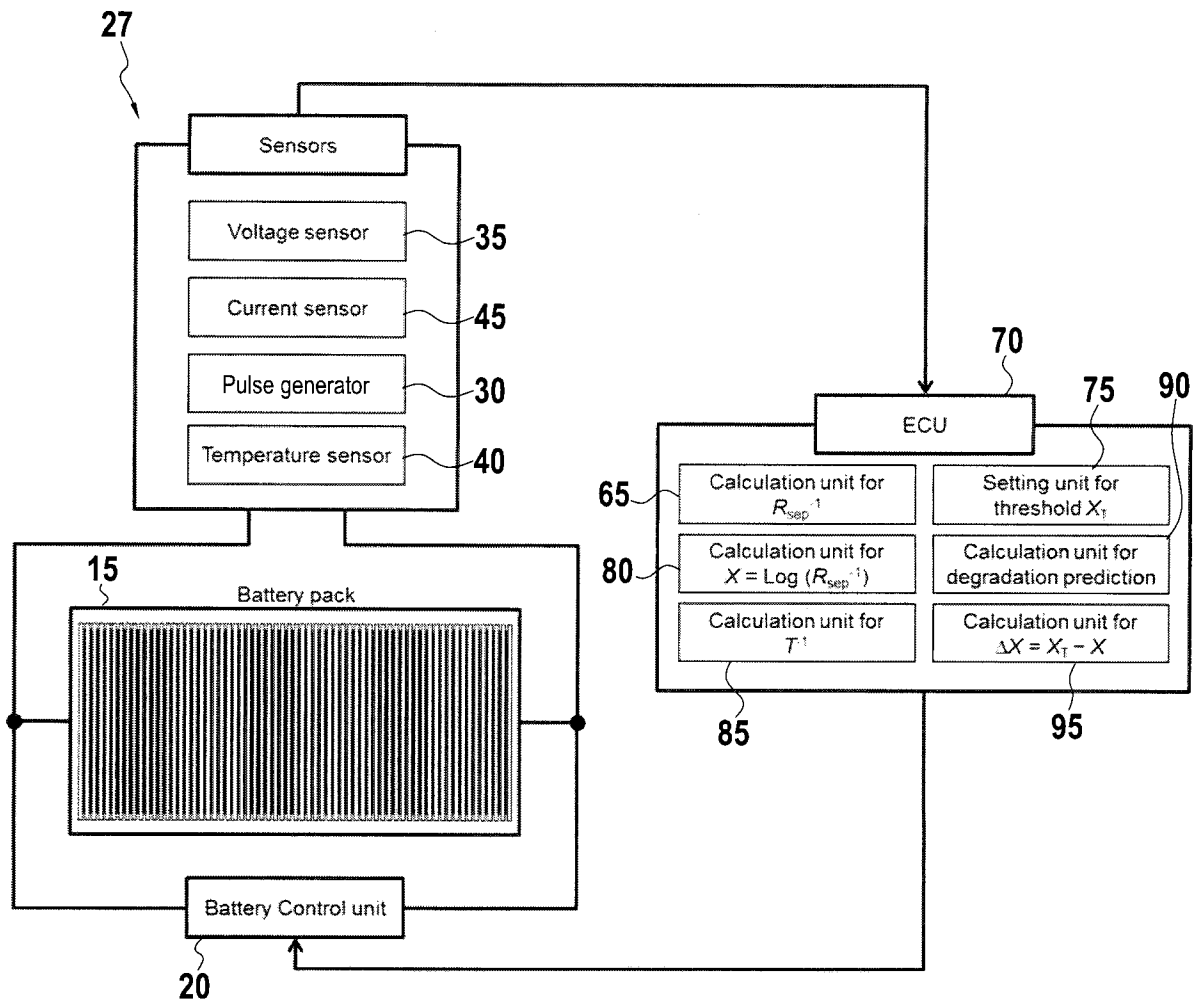


FIG.1

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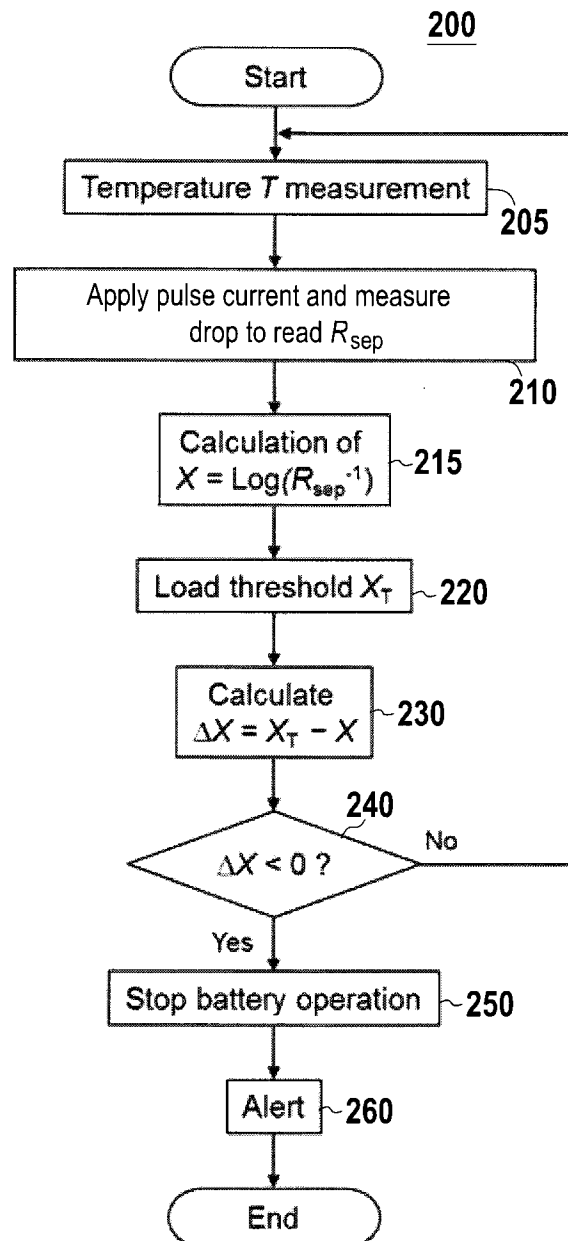


FIG.2

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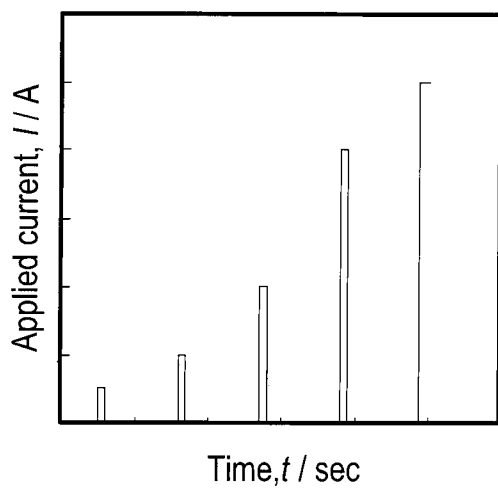


FIG. 3A

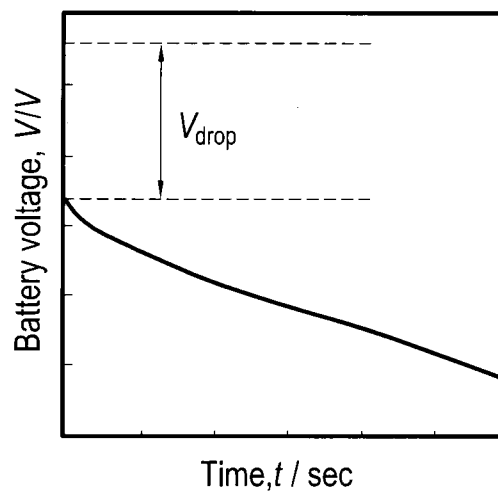


FIG. 3B

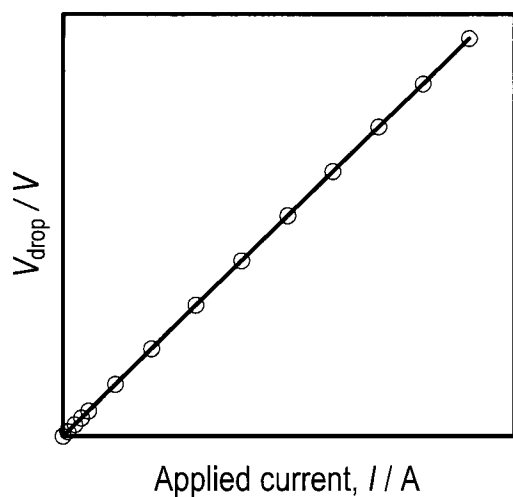


FIG. 3C

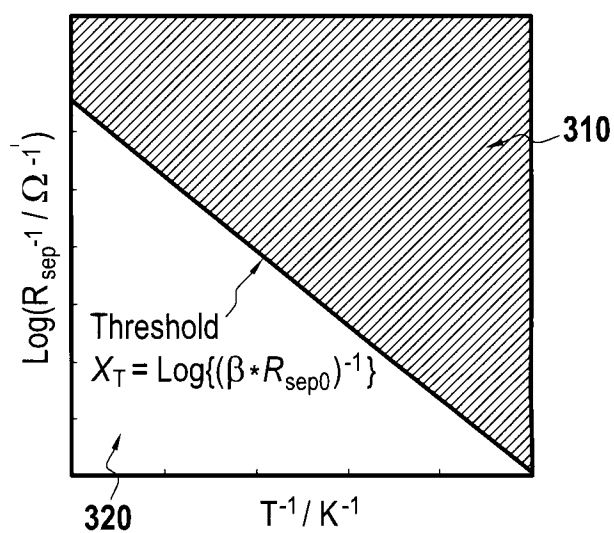


FIG. 3D

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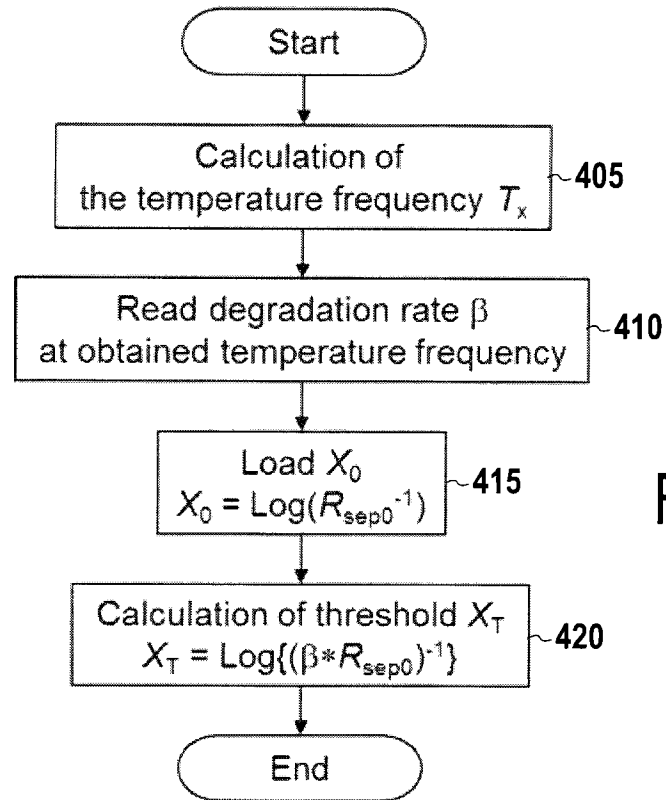


FIG.4

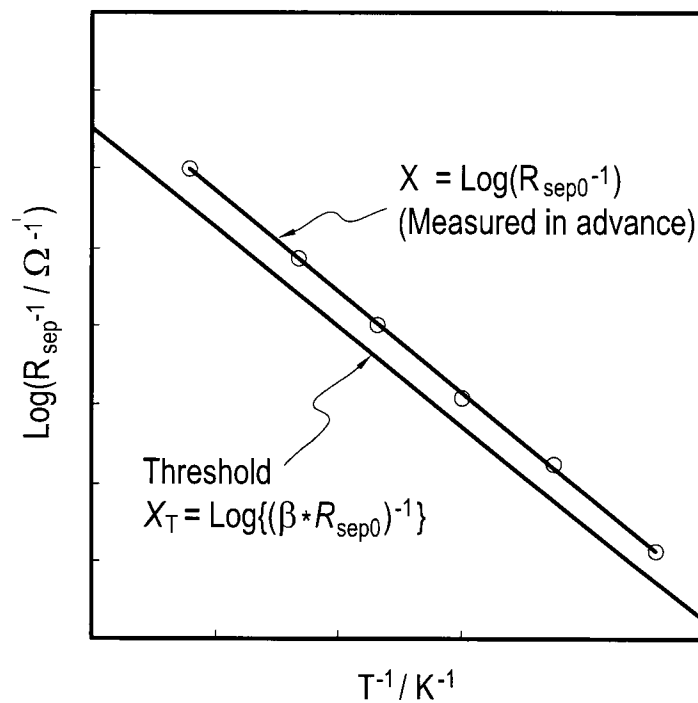


FIG.5

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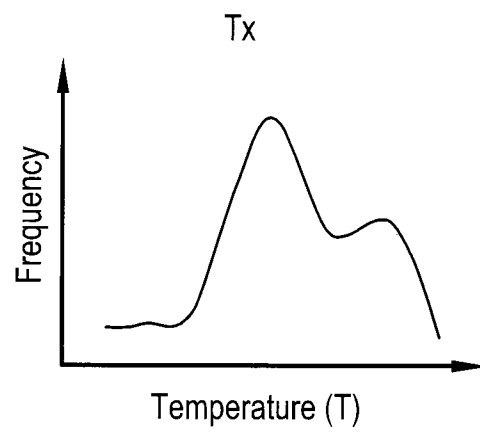


FIG.6

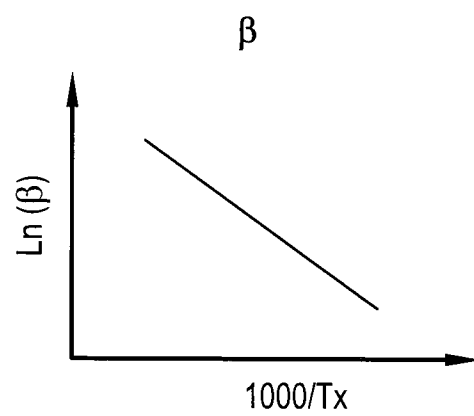


FIG.7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/053598

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01R31/36 H01M10/44 H01M10/48
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01R H01M

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

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

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/338471 A1 (ICHIKAWA KOICHI [JP] ET AL) 26 November 2015 (2015-11-26) abstract; claims 1-8; figures 1-5 paragraph [0004] - paragraph [0011] paragraph [0013] - paragraph [0019] -----	1-19
A	US 2007/252601 A1 (SATO TOSHIYUKI [JP] ET AL) 1 November 2007 (2007-11-01) claims 1-21; figures 1-4 paragraph [0010] - paragraph [0164] paragraph [0209] - paragraph [0518] -----	1-19



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

7 November 2016

Date of mailing of the international search report

14/11/2016

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Authorized officer

Nadal, Rafael

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/053598

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