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United States Patent	12388286
Kind Code	B2
Date of Patent	August 12, 2025
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Charge control device

Abstract

A charge control device calculates a learning command value of a charging parameter used in a learning phase, operates a charger in the learning phase to control the charging parameter to the learning command value, calculates a learning temperature rise rate, based on the temperature of the secondary battery, calculates a charging-time temperature rise rate in a charging phase that follows the learning phase, prior to the start of the charging phase, based on a limit temperature of the secondary battery and a duration of the charging phase, calculates a charging command value of a charging parameter which is used during a period from the start to the end of the charging phase, based on the learning command value, the learning temperature rise rate, and the charging-time temperature rise rate, and operates the charger in the charging phase to control the charging parameter to the charging command value.

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Appl. No.:	17/743736
Filed:	May 13, 2022

Prior Publication Data

Document Identifier	Publication Date
US 20220278545 A1	Sep. 01, 2022

Foreign Application Priority Data

JP	2019-205714	Nov. 13, 2019
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Related U.S. Application Data

continuation parent-doc WO PCT/JP2020/042148 20201111 PENDING child-doc US 17743736

Publication Classification

Int. Cl.: **B60L53/62** (20190101); **B60L53/60** (20190101); **B60L58/12** (20190101); **H01M10/44** (20060101); **H02J7/00** (20060101)

U.S. Cl.:

CPC **H02J7/007194** (20200101); **B60L53/60** (20190201); **B60L58/12** (20190201); **H01M10/443** (20130101); **H02J7/0048** (20200101); B60L2240/545 (20130101)

Field of Classification Search

CPC: H02J (7/007194); H02J (7/0048); H02J (7/0047); H02J (7/0071); B60L (53/60); B60L (58/12); B60L (2240/545); B60L (2240/547); B60L (2240/549); B60L (2260/46); B60L (58/24); B60L (53/62); H01M (10/443); H01M (10/44); H01M (10/486); H01M (10/48)

USPC: 320/152

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) The present application is a continuation application of International Application No. PCT/JP2020/042148, filed on Nov. 11, 2020, which claims priority to Japanese Patent Application No. 2019-205714, filed on Nov. 13, 2019. The contents of these applications are incorporated herein by reference in their entirety.

BACKGROUND

Technical Field

(1) The present disclosure relates to charge control devices that perform charge control for secondary batteries.

Background Art

(2) In a charge control device, charging current of a secondary battery is controlled to its command current so that the temperature of the secondary battery does not exceed the limit temperature.

SUMMARY

(3) In the present disclosure, provided is a charge control device as the following.

(4) The charge control device calculates a learning command value of a charging parameter used in a learning phase, operates a charger in the learning phase to control the charging parameter to the learning command value, calculates a learning temperature rise rate, based on the temperature of the secondary battery, calculates a charging-time temperature rise rate in a charging phase that follows the learning phase, prior to the start of the charging phase, based on a limit temperature of the secondary battery and a duration of the charging phase, calculates a charging command value of a charging parameter which is used during a period from the start to the end of the charging phase, based on the learning command value, the learning temperature rise rate, and the charging-time temperature rise rate, and operates the charger in the charging phase to control the charging parameter to the charging command value.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The aim set forth above and other aims, features, and advantageous effects of the present disclosure will become clearer from the following detailed description given referring to the accompanying drawings. In the drawings:

(2) FIG. 1 is a diagram illustrating an overall configuration of a vehicle-mounted charging system according to a first embodiment;

(3) FIG. 2 is a diagram illustrating a control unit and a sensor and the like as the peripheral components;

(4) FIG. 3 is a flow diagram illustrating charge control processing;

(5) FIG. 4 is a flow diagram illustrating correction processing;

(6) FIG. 5 is a diagram illustrating a relationship between temperature deviation and correction amount;

(7) FIGS. 6A to 6C are a joint timing diagram illustrating an example of charge control processing;

(8) FIG. 7 is a flow diagram illustrating charge control processing according to a second embodiment;

(9) FIG. 8 is a flow diagram illustrating charge control processing; and

(10) FIGS. 9A to 9B are a joint timing diagram illustrating an example of charge control processing.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

(11) As this type of control devices, there is known one as shown in PTL 1 in which charging

current of a secondary battery is controlled to its command current so that the temperature of the secondary battery does not exceed the limit temperature. Specifically, this control device calculates a command current based on the limit temperature, internal resistance of the secondary battery, and charging period of the secondary battery. Thus, the secondary battery is prevented from being brought into an overheated state during charge control.

(12) PTL 1: JP 2017-108522 A

(13) Secondary batteries will degrade over time. If time degradation occurs, temperature characteristics of the secondary battery when charged can change. Also, every time the secondary battery is charged, ambient temperature of the secondary battery can change. Accordingly, the influence of time degradation or ambient temperature of the secondary battery is required to be considered to appropriately calculate a command value of the charging current or the charging power of the secondary battery, which would not allow the temperature of the secondary battery to exceed the limit temperature.

(14) The present disclosure mainly aims to provide a charge control device which is capable of enhancing the accuracy of calculating a command value of the charging current or the charging power of a secondary battery, which would not allow the temperature of the secondary battery to exceed the limit temperature.

(15) In the present disclosure, a charge control device is configured to be applied to a system including a secondary battery and a charger electrically connected to the secondary battery and cause the charger to control a charging parameter that is either of charging current and charging power of the secondary battery.

(16) The charge control device includes: a learning command value calculation unit configured to calculate a learning command value of the charging parameter used in a learning phase that is an initial period of a charge control period of the secondary battery, based on a temperature of the secondary battery; a learning-time operation unit configured to operate the charger in the learning phase to control the charging parameter to the learning command value; a learning temperature rise rate calculation unit configured to calculate a learning temperature rise rate that is a temperature rise rate of the secondary battery in the learning phase, based on a temperature of the secondary battery; a charging-time temperature rise rate calculation unit configured to calculate a charging-time temperature rise rate that is a temperature rise rate of the secondary battery in a charging phase that follows the learning phase in the charge control period, prior to start of the charging phase, based on a limit temperature of the secondary battery and a duration of the charging phase; a charging command value calculation unit configured to calculate a charging command value of the charging parameter, which is used during a period from start to end of the charging phase, based on the learning command value, the learning temperature rise rate, and the charging-time temperature rise rate; and a charging-time operation unit configured to operate the charger in the charging phase to control the charging parameter to the charging command value.

(17) In the present disclosure, a learning temperature rise rate, which is a temperature rise rate of the secondary battery in the case where the charging parameter is controlled to the learning command value, is calculated in the learning phase which is set in an initial period of a charge control period of the secondary battery. Using the learning command value and the learning temperature rise rate, appropriate temperature variation characteristics of the secondary battery can be quantified, incorporating the current deterioration state and ambient temperature of the secondary battery.

(18) In the present disclosure, a charging-time temperature rise rate, which is a temperature rise rate of the secondary battery in the charging phase that follows the learning phase, is calculated based on the limit temperature of the secondary battery and duration of the charging phase. Then, in addition to the charging-time temperature rise rate, the learning command value and the learning temperature rise rate are used for calculating a charging command value. Since the learning command value and the learning temperature rise rate are calculated in the learning phase set in the

same charge control period, they are values quantifying appropriate temperature variation characteristics of the secondary battery with the incorporation of the current deterioration state and ambient temperature thereof. Accordingly, use of the learning command value and the learning temperature rise rate in addition to the charging-time temperature rise rate can lead to calculation of an appropriate charging command value incorporating the current deterioration state and ambient temperature of the secondary battery. Consequently, high accuracy can be secured for calculating a charging command value which would not allow the temperature of the secondary battery to exceed the limit temperature in the charging phase.

(19) Furthermore, prior to the start of the charging phase in the present disclosure, a charging command value is calculated which is used during the period from the start to the end of the charging phase, so that the calculated charging command value can be basically used in the charging phase. Thus, the period from the start to the end of charging the secondary battery is prevented from significantly deviating from the charge control period.

First Embodiment

(20) Referring to the drawings, a first embodiment of a charge control device according to the present disclosure will be described. The charge control device according to the present embodiment is installed to a vehicle.

(21) As shown in FIG. 1, a vehicle **10** includes a secondary battery **11** and a rotary electric machine **12**. The secondary battery **11** may be, for example, a lithium ion battery, or nickel metal hydride battery or nickel hydrogen battery, which is assumed to be a battery pack in the present embodiment. The rotary electric machine **12** is driven with power supplied from the secondary battery **11** to serve as a travelling power source of the vehicle **10**.

(22) The vehicle **10** includes a battery monitor **13**, a charger **14** and a control unit **15**. The battery monitor **13** detects a terminal voltage or the like of each battery cell forming the secondary battery **11**, and calculates a state of charge (SOC) or the like of each battery cell. The charger **14** is a device that charges electrical power supplied from power supply equipment, which is set up outside the vehicle **10**, to the secondary battery **11**.

(23) As shown in FIG. 2, the vehicle **10** includes a temperature sensor **20**, a voltage sensor **21**, and a current sensor **22**. The temperature sensor **20** detects a temperature of the secondary battery **11**, the voltage sensor **21** detects a terminal voltage of the secondary battery **11**, and the current sensor **22** detects a current passing through the secondary battery **11**. The detected values of the sensors **20** to **22**, and the information on SOC of the secondary battery **11** calculated by the battery monitor **13**, and other information are inputted to the control unit **15**.

(24) The control unit **15** performs charge control processing to control charging from the charger **14** to the secondary battery **11**, based on the detected values and information inputted therein. It should be noted that the functions of the control unit **15** can be provided by, for example, software recorded on a tangible memory device and a computer executing the software, hardware, or a combination of these.

(25) Next, a description will be given of charge control processing for the secondary battery **11** executed by the control unit **15**. In the present embodiment, a charge control period for the secondary battery **11** includes a learning phase, constant current charging phase (corresponding to the charging phase), and constant voltage charging phase.

(26) FIG. 3 shows the charge control processing performed for the secondary battery **11**.

(27) At step **S10**, it is determined whether there is charging permission for the secondary battery **11**. If it is determined that there is charging permission, charging of the secondary battery **11** is started so that charging current begins to pass through the secondary battery **11**.

(28) At the subsequent step **S11**, it is determined whether learning processing is inhibited. In the present embodiment, if at least one of the following first to third requirements is determined to be met, it is determined that the learning processing is inhibited.

(29) The first condition is that the charging current of the secondary battery **11** detected by the

current sensor **22** (termed detected charging current I_{chr} hereinafter) is equal to or less than a predetermined current I_j . This condition is for determining that the current charging mode is the normal charging mode and not the fast charging mode. In other words, in the present embodiment, execution of the learning processing is inhibited if the charging mode is the normal charging mode.

(30) The second condition is that the terminal voltage of the secondary battery **11** detected by the voltage sensor **21** (termed detected voltage V_{br} hereinafter) is equal to or higher than a predetermined voltage V_j . This condition is for determining whether the learning phase can be secured during the charge control period. In other words, in the present embodiment, a sufficient period as the learning phase cannot be secured if the detected voltage V_{br} is higher than a certain level, because the constant voltage charging phase is started when the detected voltage V_{br} has reached a target voltage V_{tgt} . It should be noted that the predetermined voltage V_j may be set, for example, to a value equal to or slightly lower than the target voltage V_{tgt} .

(31) The third condition is that the temperature of the secondary battery **11** detected by the temperature sensor **20** (termed detected temperature T_{br} hereinafter) is equal to or higher than a predetermined temperature T_j . This condition is for determining whether there is a risk of the secondary battery **11** undergoing charge control processing being brought into an overheated state. It should be noted that the processing of step **S11** corresponds to the inhibition determination unit.

(32) If it is determined at step **S11** that learning processing has not been inhibited, control proceeds to step **S12** where it is determined whether conditions for starting the learning processing have been satisfied. In the present embodiment, if the variation amount of the detected charging current I_{chr} is determined to be equal to or smaller than a predetermined variation amount, the charging current is determined to be stable and thus it is determined that conditions for starting the learning processing have been satisfied.

(33) If it is determined at step **S12** that starting conditions have been satisfied, control proceeds to step **S13** where the learning phase is started. At step **S13**, the detected temperature T_{br} and SOC of the secondary battery **11** are acquired, based on which, a command learning current I_{st} (corresponding to the learning command value) that is a command of charging current of the secondary battery **11** in the learning phase is calculated. The command learning current I_{st} may be calculated, for example, to have a smaller value, as the detected temperature T_{br} moves away from a reference temperature of around 0°C . toward a lower temperature side or a higher temperature side. Also, the command learning current I_{st} may be calculated, for example, to have a larger value as SOC becomes higher.

(34) It should be noted that the command learning current I_{st} may be calculated, for example, based on map information in which the command learning current I_{st} is specified in relation to the detected temperature T_{br} and SOC. This map information is stored in a memory **15a** provided to the control unit **15**. The memory **15a** is a non-transitory tangible recording medium other than ROM (e.g., nonvolatile memory other than ROM).

(35) Then, at step **S13**, processing is started in which the calculated command learning current I_{st} is set as a target current I_{tgt} so that the detected charging current I_{chr} (corresponding to the charging parameter) is feedback-controlled to the target current I_{tgt} with the operation of the charger **14**. Thus, charging of the secondary battery **11** is started at the command learning current I_{st} . It should be noted that, in the present embodiment, the processing of step **S13** corresponds to the learning command value calculation unit and the learning-time operation unit.

(36) At step **S14**, based on the detected temperature T_{br} , it is determined whether the amount of temperature rise ΔT_r has become a determined amount of rise ΔT_α (e.g., 0.5°C .) since the beginning of charging the secondary battery **11** at the command learning current I_{st} in the processing of step **S13**.

(37) If an affirmative determination is made at step **S14**, control proceeds to step **S15** where a learning period T_A is calculated, which is a period from the beginning of charging the secondary battery **11** at the command learning current I_{st} in the processing of step **S13** until the affirmative

determination made at step S14. Then, the determined amount of rise $\Delta T\alpha$ is divided by the calculated learning period TA to calculate a learning temperature rise rate dTst. The processing of step S15 corresponds to the learning temperature rise rate calculation unit.

(38) At step S16, a charging-time temperature rise rate dTf is calculated using the following equation (eq1), based on a limit temperature Tlimit of the secondary battery 11, an initial temperature Tini that is the detected temperature Tbr acquired currently, and a determined period TL.

(39) [Math. 1] $dTf = \frac{T_{\text{limit}} - T_{\text{ini}}}{TL}$ (eq1)

(40) In the present embodiment, the determined period TL is set to an assumed value corresponding to the duration of the constant current charging phase. Since the durations of the constant current charging phase can vary depending on SOC or the like of the secondary battery 11 before the start of charging, the actual duration of the constant current charging phase can be deviated from the above assumed value. The limit temperature Tlimit is set to, for example, an allowable upper limit temperature of the secondary battery 11 with which deterioration of the secondary battery 11 can be avoided.

(41) At step S16, a command charging current I* (corresponding to the charging command value) is calculated using the following equation (eq2), based on the calculated charging-time temperature rise rate dTf, the learning temperature rise rate dTst calculated at step S15, and the command learning current Ist calculated at step S13.

(42) [Math. 2] $I^* = I_{\text{st}} \sqrt{\frac{dTf}{dTst}}$ (eq2)

(43) The equation (eq2) has been derived by setting a condition R1=R2 on the following equation (eq3) which indicates a relationship of the amount of heat generation and temperature rise rate of the secondary battery 11 in the learning phase, with the amount of heat generation and temperature rise rate of the secondary battery 11 in the constant current charging phase. R1 indicates internal resistance of the secondary battery 11 in the learning phase, and R2 indicates internal resistance of the secondary battery 11 in the constant current charging phase.

(44) [Math. 3] $\frac{I_{\text{st}}^2 \cdot \text{Math. } R_1}{I^{*2} \cdot \text{Math. } R_2} = \frac{dTf}{dTst}$ (eq3)

(45) Since variation in ambient temperature: and internal resistance of the secondary battery 11 can be neglected in a short-duration charging process, the equation (eq3) can be approximately expressed as the equation (eq2). It should be noted that the processing of step S16 corresponds to the charging-time temperature rise rate calculation unit and the charging command value calculation unit.

(46) Then, at step S17, processing is started in which the calculated command charging current I* is set as the target current Itgt so that the detected charging current Ichr is feedback-controlled to the target current Itgt with the operation of the charger 14. Thus, the constant current charging phase is started to start charging the secondary battery 11 at the command charging current I*. It should be noted that, in the present embodiment, the processing of step S17 corresponds to the charging-time operation unit.

(47) In the present embodiment, the command charging current I* calculated at step S16 is basically used as the target current Itgt from the start of the constant current charging phase until the lapse of the determined period TL. This is because, in the present embodiment, the vehicle 10 is equipped with neither a fan nor a cooling device, such as a cooling channel, for cooling the secondary battery 11. In other words, in this case, if the temperature of the secondary battery 11 increases during charging of the secondary battery 11, the increased temperature cannot be decreased quickly and the temperature of the secondary battery 11 may exceed the limit temperature Tlimit. In particular, if charging is performed while the vehicle is stopped, the effect of cooling the secondary battery, which would be exerted while the vehicle 10 is travelling, cannot be expected and thus it is highly likely that the temperature of the secondary battery 11 will exceed the

limit temperature T_{limit} . Accordingly, a command charging current I^* that will not allow the temperature of the secondary battery **11** to exceed the limit temperature T_{limit} is determined prior to the start of the constant current charging phase, so that the command charging current I^* is basically used as the target current I_{tgt} in the constant current charging phase.

(48) At the subsequent step **S18**, correction processing is performed. FIG. 4 shows the correction processing.

(49) At step **S30**, an estimated temperature T_{est} of the secondary battery **11** is calculated based on the initial temperature T_{ini} , the charging-time temperature rise rate dT_f , and elapsed time since the start of charging the secondary battery **11** at the command charging current I^* in the processing of step **S17**. Specifically, the estimated temperature T_{est} is calculated by adding the initial temperature T_{ini} to the multiplied value of the charging-time temperature rise rate dT_f and the elapsed time. It should be noted that the processing of step **S30** corresponds to the temperature estimation unit.

(50) At step **S31**, the estimated temperature T_{est} is subtracted from the currently acquired detected temperature T_{br} to calculate a temperature deviation T_{err} .

(51) At step **S32**, it is determined whether the temperature deviation T_{err} is equal to or larger than a threshold T_{th} (>0). It should be noted that the threshold T_{th} at step **S32** corresponds to the first threshold.

(52) If an affirmative determination is made at step **S32**, control proceeds to step **S33** where a command value correction amount ΔI_{chg} is set to a negative value. Specifically, as shown in FIG. 5, as the absolute value of the positive temperature deviation T_{err} becomes larger, the absolute value of the negative command value correction amount ΔI_{chg} is set to a larger value.

(53) After completing the processing of step **S33**, control proceeds to step **S34** where the command value correction amount ΔI_{chg} set at step **S33** is added to the command charging current I^* calculated at step **S16** to calculate a corrected command charging current I^* . Thus, correction is performed to decrease the command charging current I^* calculated at step **S16**. Then, on or after this point, the corrected command charging current I^* is used as the target current I_{tgt} .

(54) If the temperature deviation T_{err} is determined to be smaller than the threshold T_{th} at step **S32**, control proceeds to step **S35** where it is determined whether the temperature deviation T_{err} is equal to or smaller than $-T_{th}$. It should be noted that $-T_{th}$ at step **S35** corresponds to the second threshold.

(55) If an affirmative determination is made at step **S35**, control proceeds to step **S36** where a command value correction amount ΔI_{chg} is set to a positive value. Specifically, as shown in FIG. 5, as the absolute value of the negative temperature deviation T_{err} becomes larger, the absolute value of the positive command value correction value ΔI_{chg} is set to a larger value.

(56) After completing the processing of step **S36**, control proceeds to step **S34** where the command value correction amount ΔI_{chg} set at step **S36** is added to the command charging current I^* calculated at step **S16** to calculate a corrected command charging current I^* . Thus, correction is performed to increase the command charging current I^* calculated at step **S16**. Then, on or after this point, the corrected command charging current I^* is used as the target current I_{tgt} . It should be noted that the processing of steps **S32** to **S36** corresponds to the correction unit.

(57) If the temperature deviation T_{err} is determined to be larger than $-T_{th}$ at step **S35**, control proceeds to step **S37** where the command value correction amount ΔI_{chg} is set to 0 (see FIG. 5). After completing the processing of step **S37**, if control proceeds to step **S34**, the command charging current I^* calculated at step **S16** is not corrected.

(58) The correction processing described above is processing performed in light of variation in SOC or temperature of the secondary battery **11** between the learning phase and the constant value charging phase, which leads to variation in internal resistance of the secondary battery **11** relying on SOC or temperature.

(59) Referring back to FIG. 3, after completing the processing of step **S18**, control proceeds to step **S19** where it is determined whether the constant current charging phase has ended. Specifically, if

the detected voltage V_{br} is determined to have reached the target voltage V_{tgt} , it is determined that the constant current charging phase has ended. If a negative determination is made at step **S19**, control returns to step **S18**. If an affirmative determination is made at step **S19**, control transfers to the constant voltage charging phase in the present embodiment. In the constant voltage charging phase, the applied voltage from the charger **14** to the secondary battery **11** is feedback-controlled to the target voltage V_{tgt} to thereby charge the secondary battery **11**.

(60) It should be noted that, if a negative determination is made at step **S12**, control transfers to the constant current charging phase without setting the learning phase. Specifically, at step **S20**, a command charging current I^* is calculated for the case where no learning phase is set. Then, at step **S21**, processing is started in which the calculated command charging current I^* is set as the target current I_{tgt} so that the detected charging current I_{chr} is feedback-controlled to the target current I_{tgt} with the operation of the charger **14**. Then, at step **S22**, correction processing is performed as in step **S18**, and at step **S23**, it is determined as in step **S19** whether the constant current charging phase has ended.

(61) FIGS. **6A-6C** show an example of charge control processing. FIG. **6A** shows changes in target current I_t , FIG. **6B** shows changes in detected voltage V_{br} , and FIG. **6C** shows changes in detected temperature T_{br} and estimated temperature T_{est} .

(62) At time t_1 , the learning phase is started and the command learning I_{st} is set as the target current I_{tgt} . After that, a learning temperature rise rate dT_{st} is calculated in the processing of step **S15**, and a charging-time temperature rise rate dT_f and a command charging current I^* are calculated in the processing of step **S16**.

(63) At time t_2 , the constant current charging phase is started and the command charging current I^* is set as the target current I_{tgt} .

(64) After that, at time t_3 , the temperature deviation T_{err} is determined to be higher than the estimated temperature T_{est} by the threshold T_{th} or more. Accordingly, correction is performed to decrease the command charging current I^* . In this case, it is preferred that the command charging current I^* is gradually changed to avoid an abrupt change of the command charging current I^* before and after the correction. After that, at time t_4 , the detected voltage V_{br} reaches the target voltage V_{tgt} and therefore the constant voltage charging phase is started.

(65) According to the present embodiment described above in detail, the following advantageous effects can be achieved.

(66) In the learning phase, a learning temperature rise rate dT_{st} is calculated, which is a temperature rise rate of the secondary battery **11** when the detected charging current I_{chr} is being feedback-controlled to the command learning current I_{st} . Based on the command learning current I_{st} and the learning temperature rise rate dT_{st} , appropriate temperature variation characteristics of the secondary battery **11** can be quantified, incorporating the current deterioration state and ambient temperature of the secondary battery **11**.

(67) After that, based on the difference between the limit temperature T_{limit} and the initial temperature T_{ini} of the secondary battery **11** and the determined period. T_L , there is calculated a charging-time temperature rise rate dT_f that is a temperature rise rate of the secondary battery **11** in the constant current charging phase following the learning phase. Thus, in addition to the charging-time temperature rise rate dT_f , the command learning current I_{st} and the learning temperature rise rate dT_{st} are used for calculating the command charging current I^* . Since the command learning current I_{st} and the learning temperature rise rate dT_{st} are calculated in the learning phase set in the same charge control period, they are values quantifying appropriate temperature variation characteristics of the secondary battery **11** with the incorporation of the current deterioration state and ambient temperature thereof. Accordingly, use of the command learning current I_{st} and the learning temperature rise rate dT_{st} in addition to the charging-time temperature rise rate dT_f can lead to calculation of an appropriate command charging current I^* incorporating the current deterioration state and ambient temperature of the secondary battery **11**. Consequently, an

appropriate command charging current I^* can be calculated so that the temperature of the secondary battery **11** will not exceed the limit temperature T_{limit} in the constant current charging phase.

(68) Furthermore, prior to the start of the constant current charging phase, a command charging current I^* is calculated which is used during the period from the start to the end of the constant current charging phase, so that the calculated command charging current I^* can be basically used during the constant current charging phase. Thus, the period from the start to the end of charging the secondary battery **11** is prevented from significantly deviating from the charge control period.

(69) The determined amount of rise ΔT_α is divided by the learning period T_A which has been required for the amount of temperature rise ΔT_r to reach the determined amount of rise ΔT_α to thereby calculate a learning temperature rise rate dT_s . According to this calculation method, the learning temperature rise rate dT_{st} is calculated after raising the temperature of the secondary battery **11** to some extent, even in the situation where the temperature of the secondary battery **11** is difficult to increase. Thus, the accuracy of calculating the learning temperature rise rate dT_{st} can be enhanced, and further, the accuracy of calculating the command charging current I^* can be enhanced. On the other hand, in the situation where the temperature of the secondary battery **11** is easy to increase, waiting time at step **S41** is shortened more than in the situation where temperature rise is difficult, and accordingly the end of the learning phase comes earlier.

(70) If the learning processing is determined to be inhibited at step **S11**, control transfers to the constant current charging phase, not to the learning phase. Thus, the learning processing is prevented from being executed in the situation where the accuracy of calculating the command learning current I_{st} and the learning temperature rise rate dT_{st} is lowered.

(71) After the start of the constant current charging phase, if the temperature deviation T_{err} , which is the difference between the detected temperature T_{br} and the estimated temperature T_{est} , is equal to or larger than the threshold T_{th} , correction is performed to decrease the command charging current I^* . If the temperature deviation T_{err} is equal to or smaller than $-T_{th}$, correction is performed to increase the command charging current I^* . Thus, the temperature of the secondary battery **11** can be controlled so as not to exceed the limit temperature T_{limit} even when the command charging current determined prior to the start of the constant current charging phase is deviated from an appropriate value.

Modifications of First Embodiment

(72) The absolute value of the threshold (>0) used at step **S32** of FIG. 4 may be set to a value different from the absolute value of the threshold (<0) used at step **S35**.

(73) Of the first to third conditions at step **S11** of FIG. 3, any one or two of them may be used as conditions for determining whether to inhibit the learning processing.

(74) The processing of step **S14** of FIG. 3 may be processing for calculating an amount of rise in detected temperature T_{br} from the beginning of charging the secondary battery **11** at the command learning current I_{st} in the processing of step **S13** until the lapse of a predetermined period. In this case, the learning temperature rise rate dT_{st} may be calculated, at step **S15**, by dividing the amount of rise in detected temperature T_{br} by the predetermined period.

(75) At step **S13** of FIG. 3, the detected voltage V_{br} may be used for calculating the command learning current I_{st} . Furthermore, SOC does not necessarily have to be used for calculating the command learning current I_{st} .

Second Embodiment

(76) Referring to the drawings, a second embodiment will be described focusing on differences from the first embodiment. In the present embodiment, multiple (two) learning phases are set in an initial period of the charge control period. This setting is for further enhancing the accuracy of calculating the command charging current, in light of the positive correlation (specifically, proportional relationship) established between the command learning current and the learning temperature rise rate.

(77) FIGS. 7 and 8 show charge control processing according to the present embodiment. It should be noted that, in FIGS. 7 and 8, the processing that is the same as the processing shown in FIG. 3 is given the same reference sign for the sake of convenience.

(78) If an affirmative determination is made at step S12, control proceeds to step S40. At step S40, the detected temperature Tbr and SOC are acquired, based on which, a first command learning current Ist1 for use in a first learning phase is calculated. Then, processing is started in which the calculated first command learning current Ist1 is set as the target current Itgt so that the detected charging current Ichr is feedback-controlled to the target current Itgt with the operation of the charger 14. Thus, charging of the secondary battery 11 is started at the first command learning current Ist1.

(79) At step S41, based on the detected temperature Tbr, it is determined whether the amount of temperature rise ΔTr1 has become the determined amount of rise ΔTα since the beginning of charging the secondary battery 11 at the first command learning current NO in the processing of step S40.

(80) If an affirmative determination is made at step S41, control proceeds to step S42 where a first learning period TM is calculated, which is a period from the beginning of charging the secondary battery 11 at the first command learning current Ist1 in the processing of step S40 until the affirmative determination made at step S41. Then, the determined amount of rise ΔTα is divided by the calculated first learning period TA1 to calculate a first learning temperature rise rate dTst1.

(81) At step S42, a first charging-time temperature rise rate dTf1 is calculated using the following equation (eq4), based on the limit temperature Tlimit of the secondary battery 11, a first initial temperature Tini1 that is the detected temperature Tbr acquired currently, and a first determined period TL1. The first determined period TL1 may be set to, for example, a value that is the sum of the assumed values of durations of a second learning phase and the constant current charging phase.

(82) [Math. 4]
$$dTf1 = \frac{T_{\text{limit}} - T_{\text{ini}1}}{TL1} \quad (\text{eq4})$$

(83) At the subsequent step S43, the detected temperature Tbr and SOC are acquired, based on which, a second command learning current for use in the second learning phase is calculated. In the present embodiment, the second command learning current Ist2 is set to a value larger than that of the first command learning current Ist1. Then, processing is started in which the calculated second command learning current Ist2 is set as the target current Itgt so that the detected charging current Ichr is feedback-controlled to the target current Itgt with the operation of the charger 14. Thus, charging of the secondary battery 11 is started at the second command learning current Ist2.

(84) At step S44, based on the detected temperature Tbr, it is determined whether the amount of temperature rise ΔTr2 has become the determined amount of rise ΔTα since the beginning of charging the secondary battery 11 at the second command learning current Ist2 in the processing of step S43.

(85) If an affirmative determination is made at step S44, control proceeds to step S45 where a second learning period TA2 is calculated, which is a period from the beginning of charging the secondary battery 11 at the second command learning current Ist2 in the processing of step S43 until the affirmative determination made at step S44. Then, the determined amount of rise ΔTα is divided by the calculated second learning period TA2 to calculate a second learning temperature rise rate dTst2.

(86) At step S45, a second charging-time temperature rise rate dTf2 is calculated using the following equation (eq5), based on the limit temperature Tlimit of the secondary battery 11, a second initial temperature Tini2 that is the detected temperature Tbr acquired currently, and a second determined period TL2. In the present embodiment, the second determined period TL2 is set to an assumed value corresponding to the duration of the constant current charging phase and smaller than the first determined period TL1.

(87) [Math . 5] $dTf2 = \frac{T_{limit} - T_{ini}}{TL2}^2$ (eq5)

(88) At the subsequent step **S46**, a first command charging current $I1^*$ is calculated using the following equation (eq6), based on the first charging-time temperature rise rate $dTf1$ and the first learning temperature rise rate $dTst1$ calculated at step **S42**, and the first command learning current $Ist1$ calculated at step **S40**,

(89) [Math . 6] $I1^* = Ist1 \sqrt{\frac{dTf1}{dTst1}}$ (eq6)

(90) Furthermore, a second command charging current $I2^*$ is calculated using the following equation (eq7), based on the second charging-time temperature rise rate $dTf2$ and the second learning temperature rise rate $dTst2$ calculated at step **S45**, and the second command learning current $Ist2$ calculated at step **S43**,

(91) [Math . 7] $I2^* = Ist2 \sqrt{\frac{dTf2}{dTst2}}$ (eq7)

(92) At the subsequent step **S47**, it is determined whether the calculated first command charging current $I1^*$ and second command charging current $I2^*$ are equal to each other. Specifically, if the difference in absolute value between the first and second command charging currents $I1^*$ and $I2^*$ is determined to be equal to or smaller than a determined value, they are determined to be equal to each other. This determined value is set to a very small value near 0.

(93) If the command charging currents $I1^*$ and $I2^*$ are determined to be equal to each other at step **S47**, control proceeds to step **S48** where either one of the command charging currents $I1^*$ and $I2^*$ is selected as a command charging current I^* . The reason why both of the command charging currents $I1^*$ and $I2^*$ are usable as the target current $Itgt$ is considered to be because both of the command charging currents $I1^*$ and $I2^*$ have high reliability. Specifically, since there is a proportional relationship between the command learning current and the learning temperature rise rate, the first command charging current $I1^*$ which is calculated based on the first command learning current $Ist1$ and the first learning temperature rise rate $dTst1$ basically becomes equal to the second command charging current $I2^*$ which is calculated based on the second command learning current $Ist2$ and the second learning temperature rise rate $dTst2$.

(94) Furthermore, at step **S48**, the number of learning phases in the next charge control period of the secondary battery **11** is set to 1. Thus, the processing shown in FIG. 3 of the first embodiment is performed in the next charge control. Consequently, in the next charge control, charging efficiency of the secondary battery **11** can be enhanced, and the period from the start of charging the secondary battery **11** until completion of the charging can be shortened.

(95) If the command charging currents $I1^*$ and $I2^*$ are determined not to be equal to each other at step **S47**, control proceeds to step **S49** where the command charging current $I1^*$ or $I2^*$, whichever is smaller, is selected as a command charging current I^* . Specifically, the first or second learning temperature rise rate $dTst1$ or $dTst2$, whichever is smaller, is used for calculating a command charging current used at step **S50**. According to the processing of step **S49**, a command charging current on a safer side can be used as a command charging current in the constant current charging phase, thereby preventing the occurrence of a situation in which the temperature of the secondary battery **11** exceeds the limit temperature $Tlimit$.

(96) Furthermore, at step **S49**, the number of learning phases in the next charge control period of the secondary battery **11** is maintained to be 2. Thus, the processing shown in FIGS. 7 and 8 is again performed in the next charge control.

(97) Then, at the subsequent step **S50**, the control unit **15** starts processing in which the command charging current I^* calculated at step **S48** or **S49** is set as the target current $Itgt$ so that the detected charging current $Ichr$ is feedback-controlled to the target current $Itgt$ with the operation of the charger **14**. Thus, the constant current charging phase is started to start charging the secondary battery **11** at the command charging current I^* .

(98) FIGS. 9A-9B show an example of charge control processing, FIG. 9A shows changes in target current $Itgt$, and FIG. 9B shows changes in detected temperature Tbr and estimated temperature

Test.

(99) At time **t1**, the first learning phase is started and the first command learning current **Ist1** is set as the target current **Itgt**. After that, a first learning temperature rise rate **dTst1** and a first charging-time temperature rise rate **dTf1** are calculated in the processing of step **S42**.

(100) At time **ta**, the second learning phase is started and the second command learning current **Ist2** is set as the target current **Ist2**. After that, a second learning temperature rise rate **dTst2** and a second charging-time temperature rise rate **dTf2** are calculated in the processing of step **S45**. Then, a command charging current **I*** is calculated in the processing of steps **S46** to **S50**, and at time **t2**, the constant current charging phase is started. It should be noted that, at time **t3**, correction is performed as in FIGS. **6A-6C** of the first embodiment, and at time **t4**, the constant voltage charging phase is started.

Other Embodiments

(101) The embodiments described above may be modified and implemented as follows.

(102) In the second embodiment, the first command learning current **Ist1** may be smaller than the second command learning current **Ist2**. Furthermore, the first and second command learning currents **Ist1** and **Ist2** may have the same value.

(103) In the second embodiment, the number of learning phases may be three or more.

(104) At step **S13** of FIG. **3** of the first embodiment, a command learning power **Pst** (corresponding to the learning command value), which is a command of the charging power of the secondary battery **11** in the learning phase, may be calculated based on the detected temperature **Tbr** and SOC. The command learning power **Pst** may be calculated, for example, to have a smaller value, as the detected temperature **Tbr** moves away from a reference temperature of around 0° C. toward a lower temperature side or a higher temperature side. Also, the command learning power **Pst** may be calculated, for example, to have a larger value, as SOC becomes higher.

(105) Then, processing is started in which the calculated command learning power **Pst** is set as a target power **Ptgt** so that a charging power **Pchr** (corresponding to the charging parameter) is feedback-controlled to the target power **Ptgt** with the operation of the charger **14**. It should be noted that the charging power **Pchr** may be calculated, for example, as a multiplied value of the detected charging current **Ichr** and the detected voltage **Vbr**.

(106) After that, at step **S16**, a command charging power **P*** (corresponding to the charging command value) may be calculated using the following equation (eq8), based on the calculated charging-time temperature rise rate **dTf**, the learning temperature rise rate **dTst** calculated at step **S15**, and the command learning power **Pst** calculated at step **S13**. It should be noted that, when deriving the following equation (eq8), the approximation is made so that variation in terminal voltage of the secondary battery **11** in the learning phase is ignored.

(107) [Math . 8]
$$P^* = P_{st} \sqrt{\frac{dTf}{dTst}} \quad (\text{eq8})$$

(108) Then, at step **S17**, processing is started in which the calculated command charging power **P*** is set as the target power **Ptgt** so that the charging power **Pchr** is feedback-controlled to the target power **Ptgt** with the operation of the charger **14**. Thus, a constant power charging phase (corresponding to the charging phase) is started and continued until an affirmative determination is made at step **S19**.

(109) It should be noted that the command correction amount at step **S18** is a correction amount of power, not current.

(110) The system may be provided with a second temperature sensor in the vicinity of the secondary battery **11**, targeting the components, which have correlation with the temperature of the secondary battery **11**, for temperature detection. In this case, the temperature of the secondary battery **11** for use in charge control may be calculated based on the detected value of the second temperature sensor.

(111) The present disclosure may be applied to systems that are not installed to vehicles.

(112) The control unit and the processes thereof described in the present disclosure may be implemented by a dedicated computer which is provided by configuring a processor and a memory that are programmed to perform one or more functions. Alternatively, the control unit and the processes thereof described in the present disclosure may be implemented by a dedicated computer which is provided by configuring a processor with one or more dedicated hardware logic circuits. Alternatively, the control unit and the processes thereof described in the present disclosure may be implemented by one or more dedicated computers which are configured by combining a processor and a memory that are programmed to perform one or more functions, with a processor that is configured by one or more hardware logic circuits. Furthermore, the computer programs may be stored in a computer readable non-transitory tangible recording medium, as instructions to be performed by the computer.

(113) The present disclosure has been described based on some embodiments however, the present disclosure should not be construed as being limited to these embodiments or structures. The scope of the present disclosure should encompass various modifications or equivalents. In addition, various combinations or modes, and further, other combinations or modes including one or more additional elements or fewer elements of the various combinations or modes should also be included within the category or idea of the present disclosure.

Claims

1. A charge control device configured (i) to be applied to a system, which includes a secondary battery and a charger electrically connected to the secondary battery, and (ii) to cause the charger to control a charging parameter that is either of charging current or charging power of the secondary battery, the charge control device comprising a control unit with a processor programmed to: calculate, based on a temperature of the secondary battery, a learning command value of the charging parameter used in a learning phase, which is an initial period of a charge control period of the secondary battery; operate the charger in the learning phase to control the charging parameter at the learning command value; calculate, based on a detected temperature of the secondary battery, a learning temperature rise rate, which is a temperature rise rate of the secondary battery in the learning phase during which the charger is operated to control the charging parameter at the learning command value; calculate, (i) prior to start of a charging phase that follows the learning phase in the charge control period and (ii) based on a limit temperature of the secondary battery and a duration of the charging phase, a charging-time temperature rise rate, which is a temperature rise rate of the secondary battery in the charging phase that follows the learning phase in the charge control period; calculate a charging command value of the charging parameter, which is used during a period from start to end of the charging phase, based on the learning command value, the learning temperature rise rate, and the charging-time temperature rise rate; and operate the charger in the charging phase to control the charging parameter at the charging command value.
2. The charge control device according to claim 1, wherein the processor of the control unit is programmed to calculate the charging-time temperature rise rate based on (i) a difference between an initial temperature of the secondary battery in the charging phase and the limit temperature, and (ii) a duration of the charging phase.
3. The charge control device according to claim 1, wherein the processor of the control unit is programmed to calculate the learning temperature rise rate, based on time required for an amount of temperature rise of the secondary battery to become a determined amount of rise, and the determined amount of rise.
4. The charge control device according to claim 1, wherein the processor of the control unit is programmed to determine, based on at least one of a temperature, a voltage and a charging current of the secondary battery, (i) whether to inhibit the operation of the charger in the learning phase, and (ii) whether to inhibit the calculation of the learning temperature rise rate.

5. The charge control device according to claim 1, wherein the processor of the control unit is further programmed to: estimate a temperature of the secondary battery in the charging phase, based on the charging-time temperature rise rate; acquire a temperature of the secondary battery; perform correction to decrease the calculated charging command value in a case where a temperature of the secondary battery acquired in the charging phase is higher by a first threshold or more than the estimated temperature of the secondary battery in the charging phase; and perform correction to increase the calculated charging command value in a case where the acquired temperature of the secondary battery is lower by a second threshold or more than the estimated temperature of the secondary battery in the charging phase.
 6. The charge control device according to claim 1, wherein a plurality of the learning phases are set in the initial period of the charge control period.
 7. The charge control device according to claim 6, wherein the processor of the control unit is programmed to set the learning command values used in the respective learning phases to different values.
 8. The charge control device according to claim 6, wherein the processor of the control unit is programmed to: calculate the learning temperature rise rates in the respective learning phases; determine whether the calculated learning temperature rise rates are equal to each other; and use any one of the calculated learning temperature rise rates to calculate the charging command value, in a case where the learning temperature rise rates are determined to be equal to each other.
 9. The charge control device according to claim 6, wherein the processor of the control unit is programmed to: calculate the learning temperature rise rates in the respective learning phases, phases; and determine whether the calculated learning temperature rise rates are equal to each other; and use a minimum learning temperature rise rate among the calculated learning temperature rise rates to calculate the charging command value, in a case where the learning temperature rise rates are determined not to be equal to each other.
 10. The charge control device according to claim 6, wherein the processor of the control unit is programmed to: calculate the learning temperature rise rates in the respective learning phases; determine whether the calculated learning temperature rise rates are equal to each other; and in a case where the learning temperature rise rates are determined to be equal to each other, set to 1 the number of learning phases in the next charge control period of the secondary battery.
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