US012388286B2

(12) **United States Patent**
Zhou

(10) **Patent No.: US 12,388,286 B2**
(45) **Date of Patent: Aug. 12, 2025**

(54) **CHARGE CONTROL DEVICE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 627 days.

(21) Appl. No.: **17/743,736**

(22) Filed: **May 13, 2022**

(65) **Prior Publication Data**

US 2022/0278545 A1 Sep. 1, 2022

Related U.S. Application Data

(63) Continuation of application No. PCT/JP2020/042148, filed on Nov. 11, 2020.

(30) **Foreign Application Priority Data**

Nov. 13, 2019 (JP) 2019-205714

(51) **Int. Cl.**
B60L 53/62 (2019.01)
B60L 53/60 (2019.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H02J 7/007194*** (2020.01); ***B60L 53/60*** (2019.02); ***B60L 58/12*** (2019.02);
(Continued)

(58) **Field of Classification Search**
CPC .. H02J 7/007194; H02J 7/0048; H02J 7/0047; H02J 7/0071; B60L 53/60;
(Continued)

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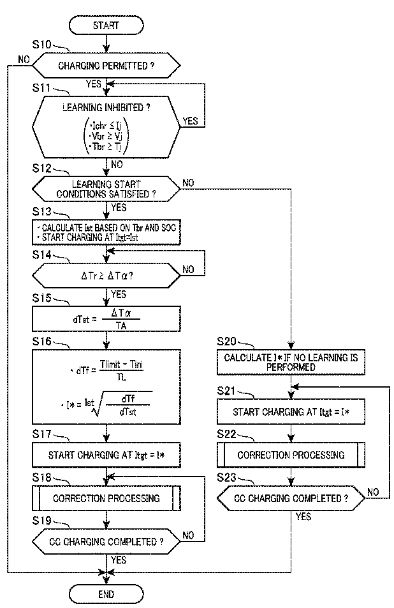
(57) **ABSTRACT**

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.

10 Claims, 7 Drawing Sheets



(51) **Int. Cl.**
B60L 58/12 (2019.01)
H01M 10/44 (2006.01)
H02J 7/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H01M 10/443*** (2013.01); ***H02J 7/0048*** (2020.01); *B60L 2240/545* (2013.01)

(58) **Field of Classification Search**
CPC 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
See application file for complete search history.

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FIG. 1

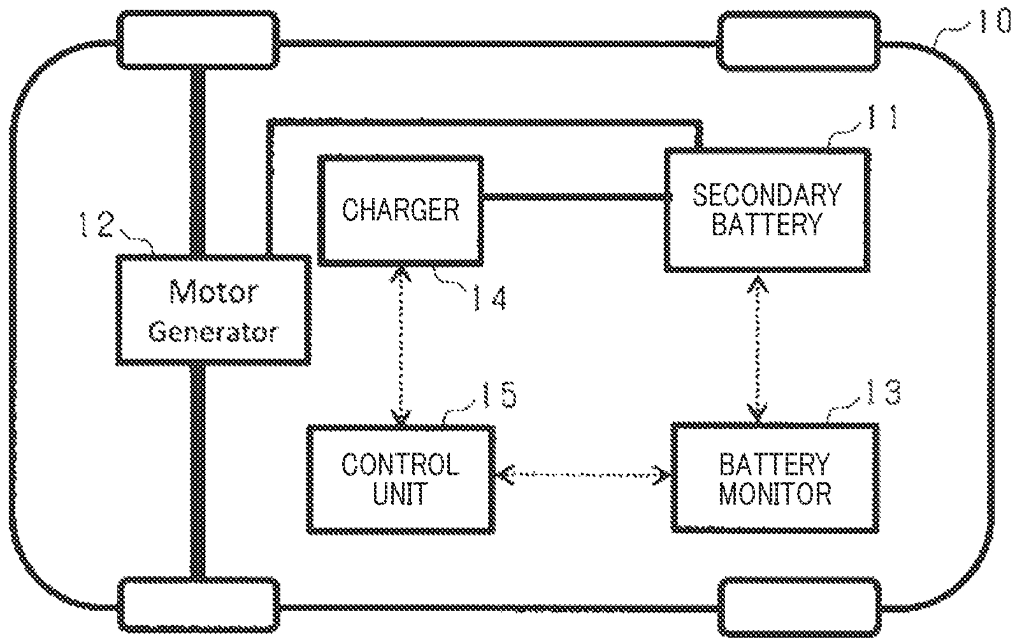

10
11
CHARGER
SECONDARY BATTERY
12
Motor Generator
14
15
13
CONTROL UNIT
BATTERY MONITOR

FIG. 2

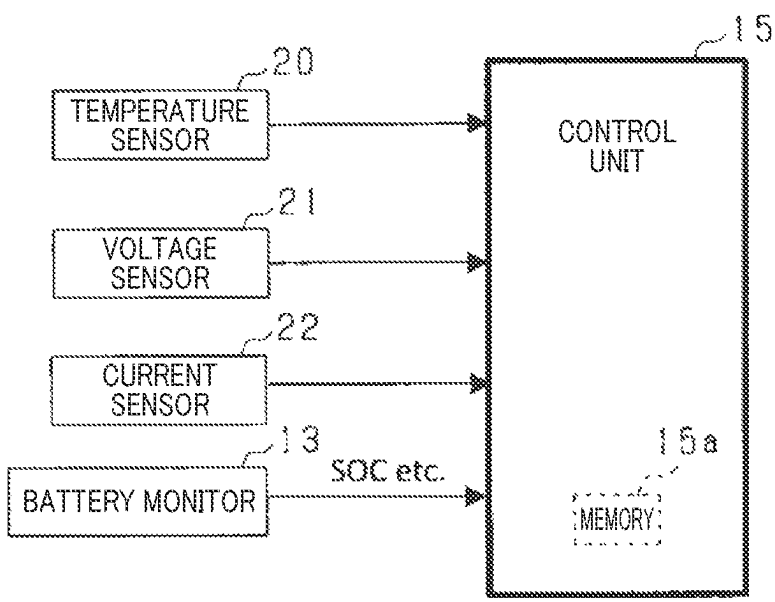
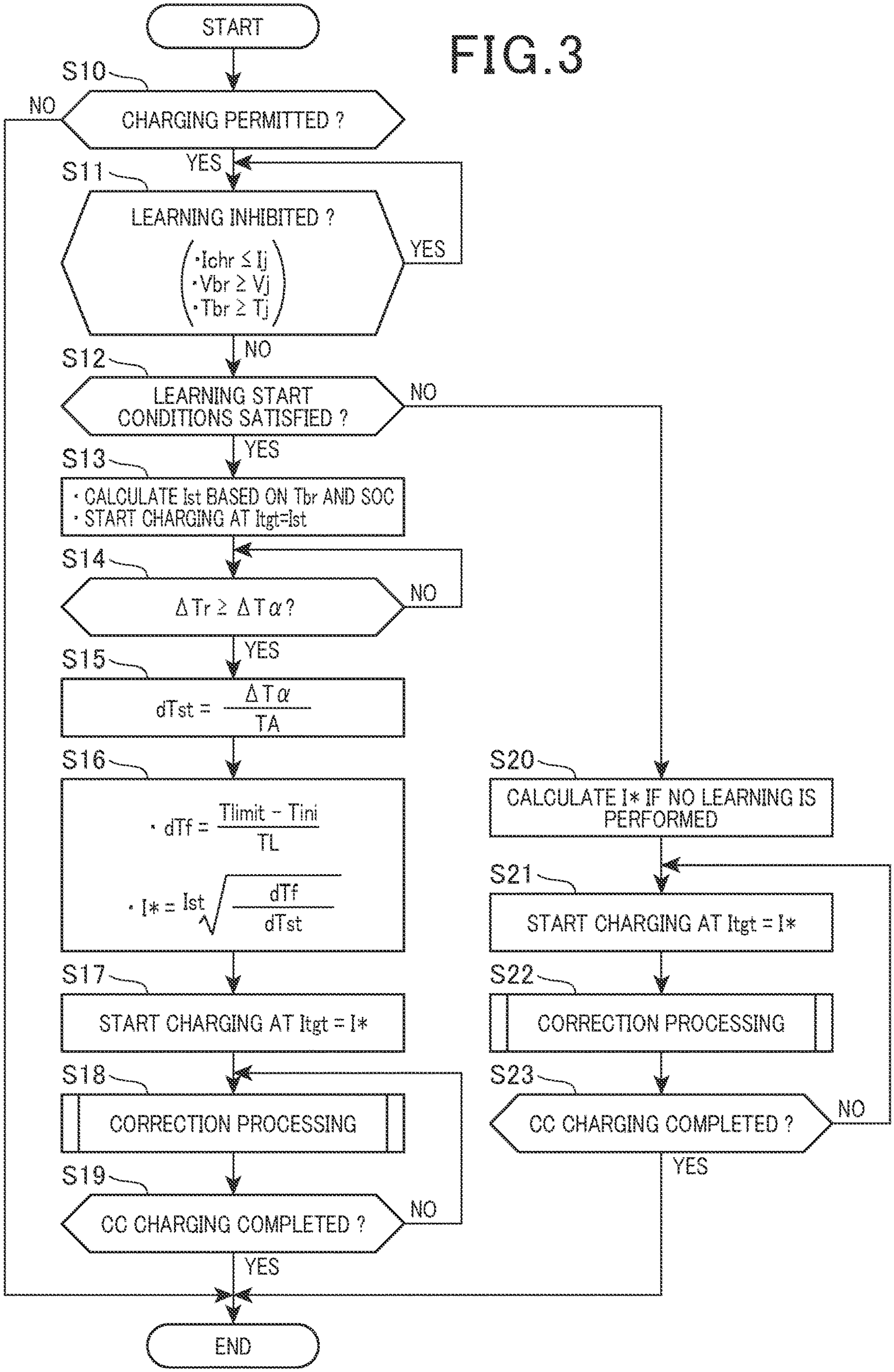

15
20
TEMPERATURE SENSOR
CONTROL UNIT
21
VOLTAGE SENSOR
22
CURRENT SENSOR
13
15a
SOC etc.
BATTERY MONITOR
MEMORY

FIG.3



START
S10
CHARGING PERMITTED ?
NO
YES
S11
LEARNING INHIBITED ?
•Ichr ≤ Ij
•Vbr ≥ Vj
•Tbr ≥ Tj
YES
NO
S12
LEARNING START CONDITIONS SATISFIED ?
NO
YES
S13
• CALCULATE Ist BASED ON Tbr AND SOC
• START CHARGING AT Itgt=Ist
S14
ΔTr ≥ ΔTα?
NO
YES
S15
dTst = ΔTα / TA
S16
• dTf = (Tlimit − Tini) / TL
• I* = Ist √(dTf / dTst)
S17
START CHARGING AT Itgt = I*
S18
CORRECTION PROCESSING
S19
CC CHARGING COMPLETED ?
NO
YES
S20
CALCULATE I* IF NO LEARNING IS PERFORMED
S21
START CHARGING AT Itgt = I*
S22
CORRECTION PROCESSING
S23
CC CHARGING COMPLETED ?
NO
YES
END

FIG.4

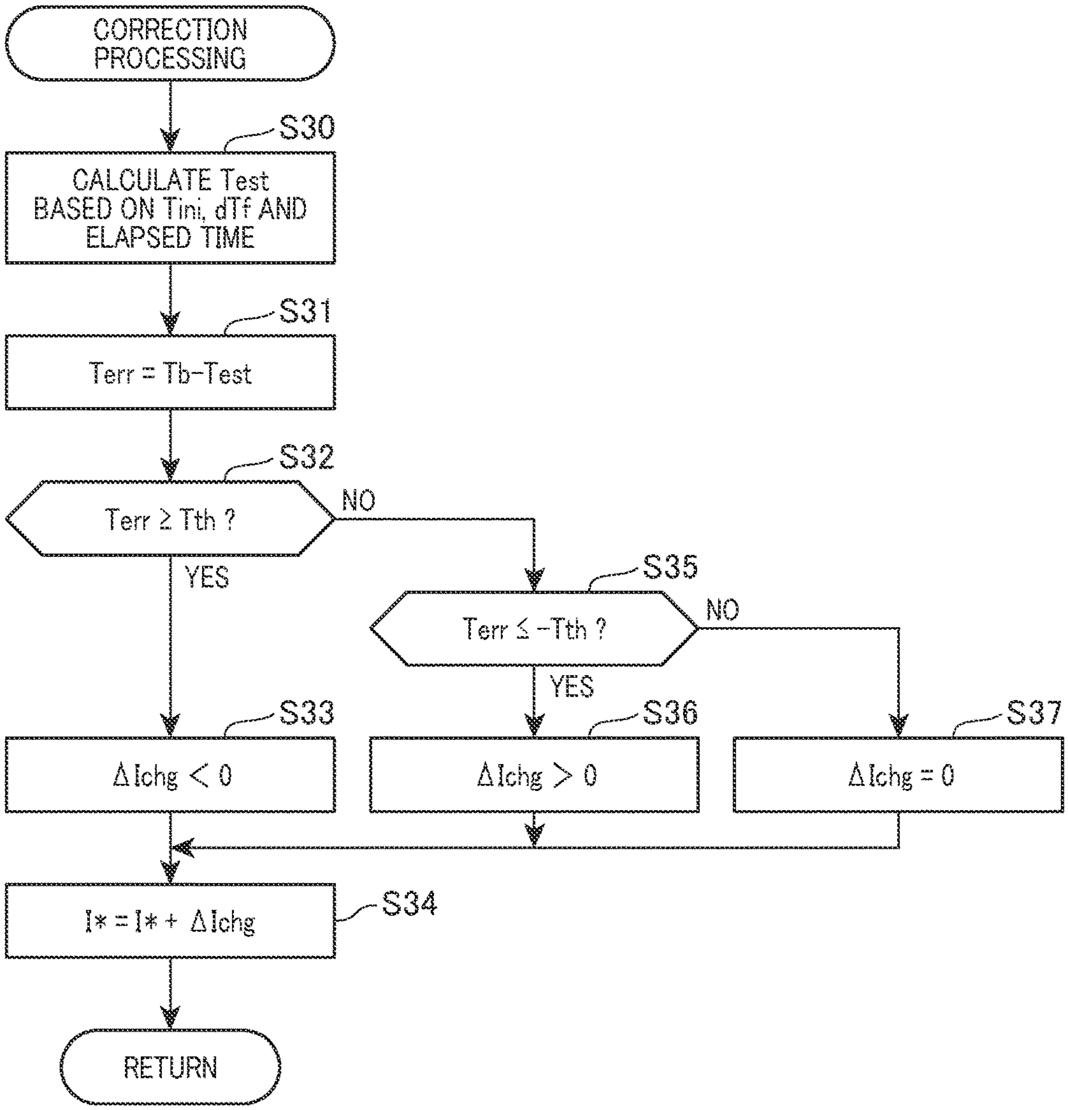
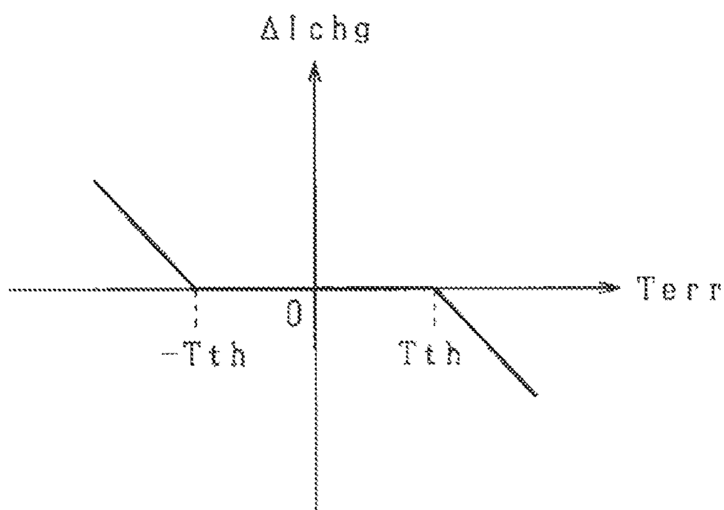

CORRECTION PROCESSING
S30
CALCULATE Test BASED ON Tini, dTf AND ELAPSED TIME
S31
Terr = Tb−Test
S32
Terr ≥ Tth ?
NO
YES
S35
Terr ≤ −Tth ?
NO
YES
S33
ΔIchg < 0
S36
ΔIchg > 0
S37
ΔIchg = 0
I* = I* + ΔIchg
S34
RETURN

FIG.5


ΔIchg
Terr
0
−Tth
Tth

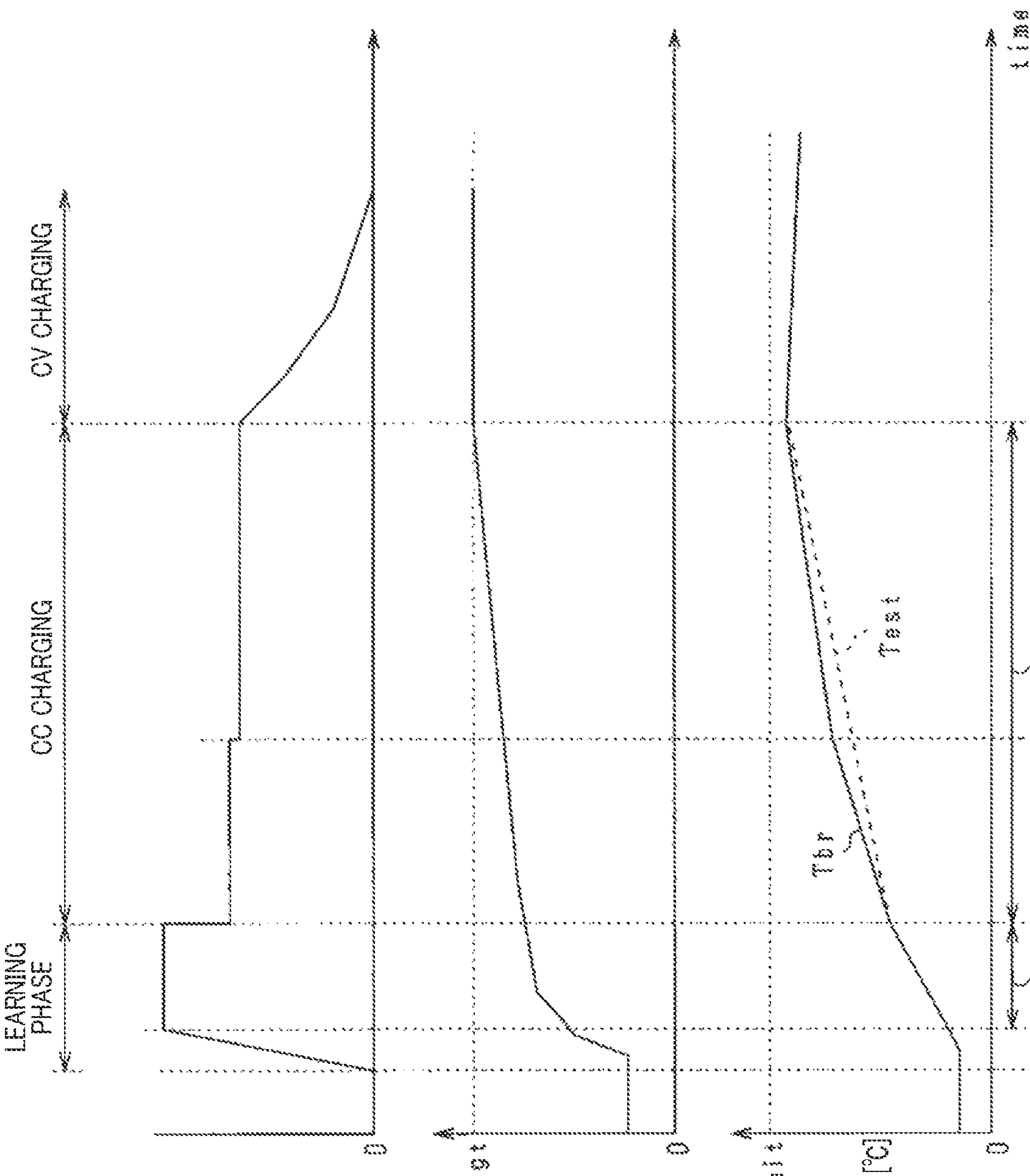


FIG.6A

FIG.6B

FIG.6C

FIG. 7

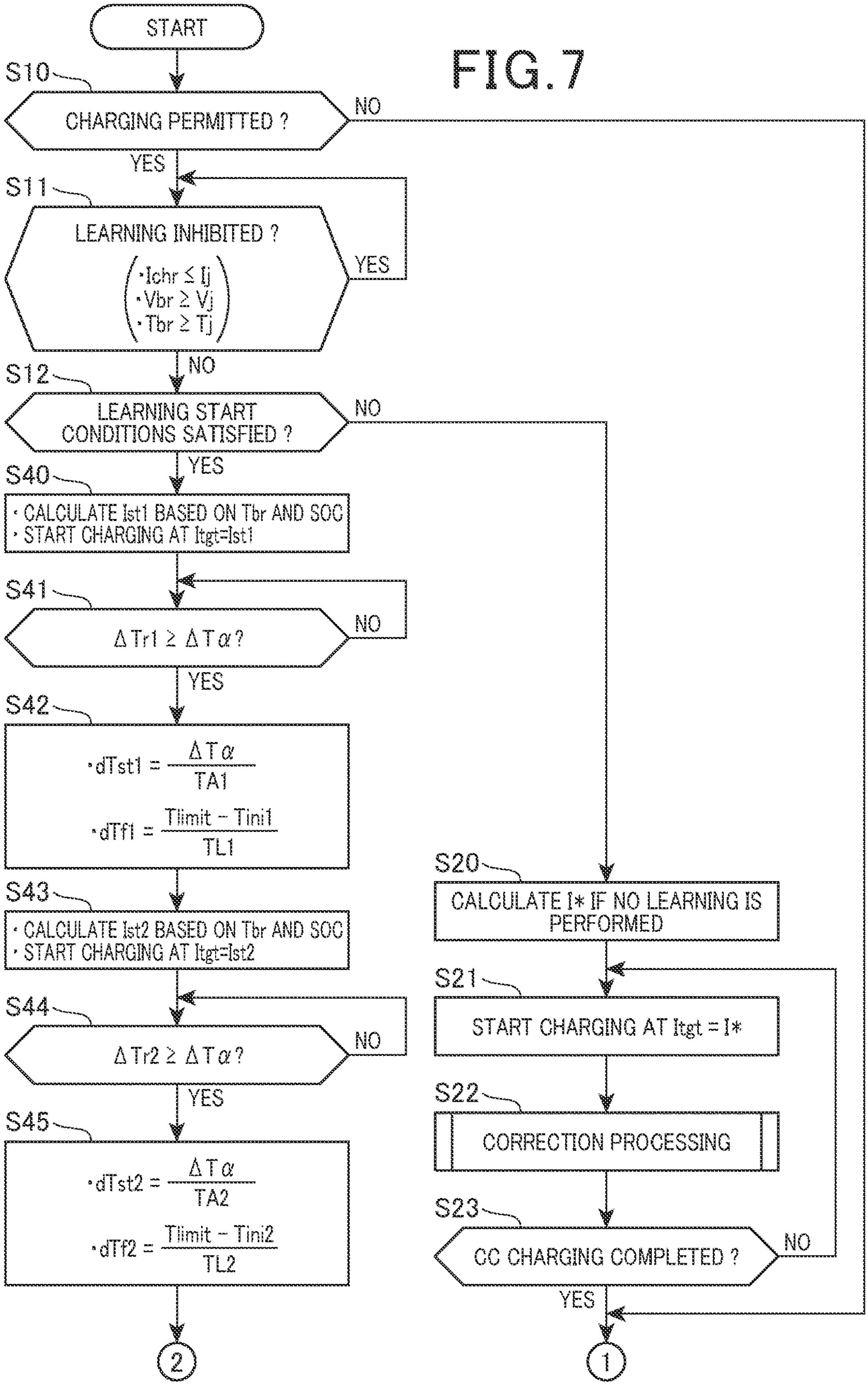
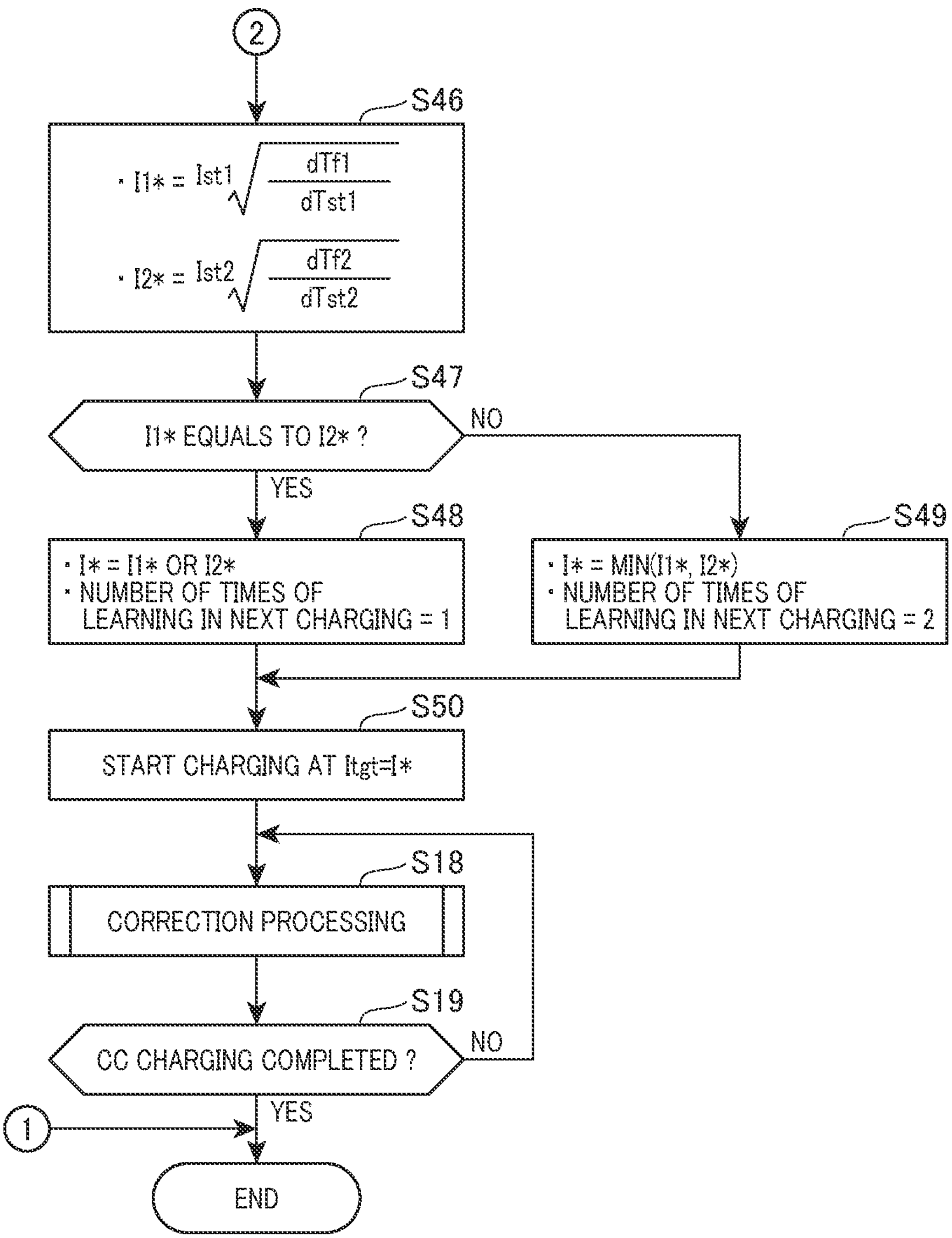

START
S10
CHARGING PERMITTED ?
NO
YES
S11
LEARNING INHIBITED ?
·Ichr ≤ Ij
·Vbr ≥ Vj
·Tbr ≥ Tj
YES
NO
S12
LEARNING START CONDITIONS SATISFIED ?
NO
YES
S40
· CALCULATE Ist1 BASED ON Tbr AND SOC
· START CHARGING AT Itgt=Ist1
S41
ΔTr1 ≥ ΔTα ?
NO
YES
S42
·dTst1 = ΔTα / TA1
·dTf1 = Tlimit − Tini1 / TL1
S43
· CALCULATE Ist2 BASED ON Tbr AND SOC
· START CHARGING AT Itgt=Ist2
S44
ΔTr2 ≥ ΔTα ?
NO
YES
S45
·dTst2 = ΔTα / TA2
·dTf2 = Tlimit − Tini2 / TL2
2
S20
CALCULATE I* IF NO LEARNING IS PERFORMED
S21
START CHARGING AT Itgt = I*
S22
CORRECTION PROCESSING
S23
CC CHARGING COMPLETED ?
NO
YES
1

FIG. 8


2
S46
· I1* = Ist1 √(dTf1/dTst1)
· I2* = Ist2 √(dTf2/dTst2)
S47
I1* EQUALS TO I2* ?
NO
YES
S48
· I* = I1* OR I2*
· NUMBER OF TIMES OF LEARNING IN NEXT CHARGING = 1
S49
· I* = MIN(I1*, I2*)
· NUMBER OF TIMES OF LEARNING IN NEXT CHARGING = 2
S50
START CHARGING AT Itgt=I*
S18
CORRECTION PROCESSING
S19
CC CHARGING COMPLETED ?
NO
YES
1
END

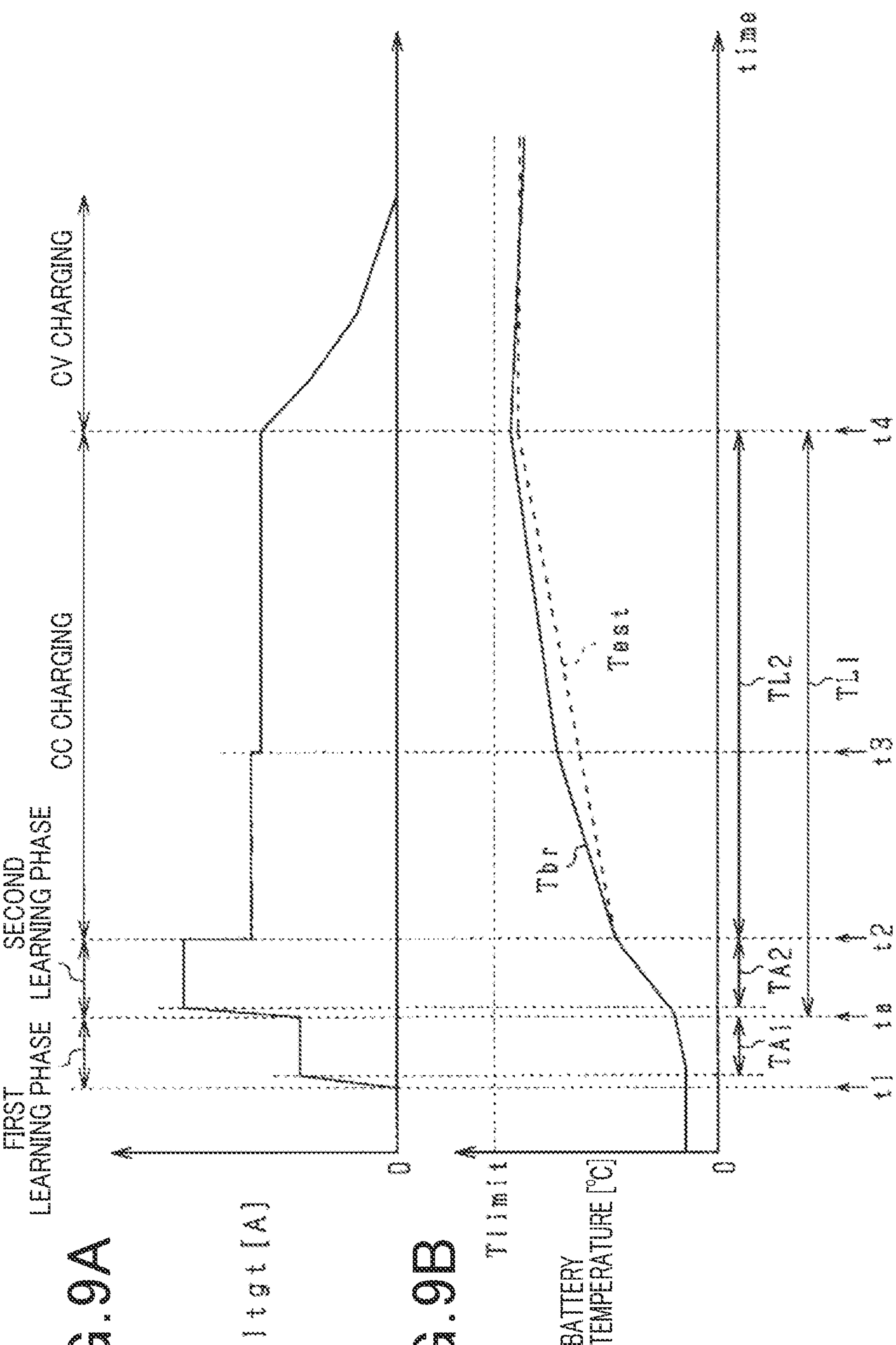

FIRST LEARNING PHASE
SECOND LEARNING PHASE
CC CHARGING
CV CHARGING
Itgt [A]
0
Tlimit
BATTERY TEMPERATURE [°C]
Tbr
Test
TA1
TA2
TL2
TL1
t1
ta
t2
t3
t4
time

FIG.9A

FIG.9B

CHARGE CONTROL DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

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

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

Background Art

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

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

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.

BRIEF DESCRIPTION OF THE DRAWINGS

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:

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

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

FIG. **3** is a flow diagram illustrating charge control processing;

FIG. **4** is a flow diagram illustrating correction processing;

FIG. **5** is a diagram illustrating a relationship between temperature deviation and correction amount;

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

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

FIG. **8** is a flow diagram illustrating charge control processing; and

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

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

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.

PTL 1: JP 2017-108522 A

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.

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.

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.

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.

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.

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.

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

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.

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**.

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**.

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**.

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.

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.

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

At step S**10**, 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**.

At the subsequent step S**11**, 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.

The first condition is that the charging current of the secondary battery **11** detected by the current sensor **22** (termed detected charging current Ichr hereinafter) is equal to or less than a predetermined current Ij. 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.

The second condition is that the terminal voltage of the secondary battery **11** detected by the voltage sensor **21** (termed detected voltage Vbr hereinafter) is equal to or higher than a predetermined voltage Vj. 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 Vbr is higher than a certain level, because the constant voltage charging phase is started when the detected voltage Vbr has reached a target voltage Vtgt. It should be noted that the predetermined voltage Vj may be set, for example, to a value equal to or slightly lower than the target voltage Vtgt.

The third condition is that the temperature of the secondary battery **11** detected by the temperature sensor **20** (termed detected temperature Tbr hereinafter) is equal to or higher than a predetermined temperature Tj. 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.

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 Ichr 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.

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 Tbr and SOC of the secondary battery **11** are acquired, based on which, a command learning current Ist (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 Ist 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 current Ist may be calculated, for example, to have a larger value as SOC becomes higher.

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

Then, at step **S13**, processing is started in which the calculated command learning current Ist is set as a target current Itgt so that the detected charging current Ichr (corresponding to the charging parameter) 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 command learning current Ist. 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.

At step **S14**, based on the detected temperature Tbr, it is determined whether the amount of temperature rise ΔTr has become a determined amount of rise ΔTα (e.g., 0.5° C.) since the beginning of charging the secondary battery **11** at the command learning current Ist in the processing of step **S13**.

If an affirmative determination is made at step **S14**, control proceeds to step **S15** where a learning period TA is calculated, which is a period from the beginning of charging the secondary battery **11** at the command learning current Ist in the processing of step **S13** until the affirmative determination made at step **S14**. Then, the determined amount of rise ΔTα 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.

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.

[Math. 1]

$$dTf = \frac{T_{limit} - T_{ini}}{TL} \tag{eq1}$$

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.

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**.

[Math. 2]

$$I* = I_{st}\sqrt{\frac{dTf}{dTst}} \tag{eq2}$$

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.

[Math. 3]

$$\frac{I_{st}^2 \cdot R_1}{I^{*2} \cdot R_2} = \frac{dTf}{dTst} \tag{eq3}$$

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.

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.

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 Tlimit. Accordingly, a command charging current I* that will not allow the temperature of the secondary battery **11** to exceed the limit temperature Tlimit 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 Itgt in the constant current charging phase.

At the subsequent step S**18**, correction processing is performed. FIG. **4** shows the correction processing.

At step S**30**, an estimated temperature Test of the secondary battery **11** is calculated based on the initial temperature Tini, the charging-time temperature rise rate dTf, and elapsed time since the start of charging the secondary battery **11** at the command charging current I* in the processing of step S**17**. Specifically, the estimated temperature Test is calculated by adding the initial temperature Tini to the multiplied value of the charging-time temperature rise rate dTf and the elapsed time. It should be noted that the processing of step S**30** corresponds to the temperature estimation unit.

At step S**31**, the estimated temperature Test is subtracted from the currently acquired detected temperature Tbr to calculate a temperature deviation Terr.

At step S**32**, it is determined whether the temperature deviation Terr is equal to or larger than a threshold Tth (>0). It should be noted that the threshold Tth at step S**32** corresponds to the first threshold.

If an affirmative determination is made at step S**32**, control proceeds to step S**33** where a command value correction amount ΔIchg is set to a negative value. Specifically, as shown in FIG. **5**, as the absolute value of the positive temperature deviation Terr becomes larger, the absolute value of the negative command value correction amount ΔIchg is set to a larger value.

After completing the processing of step S**33**, control proceeds to step S**34** where the command value correction amount ΔIchg set at step S**33** is added to the command charging current I* calculated at step S**16** to calculate a corrected command charging current I*. Thus, correction is performed to decrease the command charging current. I* calculated at step S**16**. Then, on or after this point, the corrected command charging current I* is used as the target current Itgt.

If the temperature deviation Terr is determined to be smaller than the threshold Tth at step S**32**, control proceeds to step S**35** where it is determined whether the temperature deviation Terr is equal to or smaller than −Tth. It should be noted that −Tth at step S**35** corresponds to the second threshold.

If an affirmative determination is made at step S**35**, control proceeds to step S**36** where a command value correction amount ΔIchg is set to a positive value. Specifically, as shown in FIG. **5**, as the absolute value of the negative temperature deviation Terr becomes larger, the absolute value of the positive command value correction value ΔIchg is set to a larger value.

After completing the processing of step S**36**, control proceeds to step S**34** where the command value correction amount ΔIchg set at step S**36** is added to the command charging current I* calculated at step S**16** to calculate a corrected command charging current I*. Thus, correction is performed to increase the command charging current I* calculated at step S**16**. Then, on or after this point, the corrected command charging current I* is used as the target current Itgt. It should be noted that the processing of steps S**32** to S**36** corresponds to the correction unit.

If the temperature deviation Terr is determined to be larger than −Tth at step S**35**, control proceeds to step S**37** where the command value correction amount ΔIchg is set to 0 (see FIG. **5**). After completing the processing of step S**37**, if control proceeds to step S**34**, the command charging current I* calculated at step S**16** is not corrected.

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.

Referring back to FIG. **3**, after completing the processing of step S**18**, control proceeds to step S**19** where it is determined whether the constant current charging phase has ended. Specifically, if the detected voltage Vbr is determined to have reached the target voltage Vtgt, it is determined that the constant current charging phase has ended. If a negative determination is made at step S**19**, control returns to step S**18**. If an affirmative determination is made at step S**19**, 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 Vtgt to thereby charge the secondary battery **11**.

It should be noted that, if a negative determination is made at step S**12**, control transfers to the constant current charging phase without setting the learning phase, Specifically, at step S**20**, a command charging current I* is calculated for the case where no learning phase is set. Then, at step S**21**, 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**. Then, at step S**22**, correction processing is performed as in step S**18**, and at step S**23**, it is determined as in step S**19** whether the constant current charging phase has ended.

FIGS. **6**A-**6**C show an example of charge control processing. FIG. **6**A shows changes in target current it, FIG. **6**B shows changes in detected voltage Vbr, and FIG. **6**C shows changes in detected temperature Tbr and estimated temperature Test.

At time t**1**, the learning phase is started and the command learning Ist is set as the target current Itgt. After that, a learning temperature rise rate dTst is calculated in the processing of step S**15**, and a charging-time temperature rise rate dTf and a command charging current I* are calculated in the processing of step S**16**.

At time t**2**, the constant current charging phase is started and the command charging current I* is set as the target current Itgt.

After that, at time t**3**, the temperature deviation Terr is determined to be higher than the estimated temperature Test by the threshold Tth 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 **t4**, the detected voltage Vbr reaches the target voltage Vtgt and therefore the constant voltage charging phase is started.

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

In the learning phase, a learning temperature rise rate dTst is calculated, which is a temperature rise rate of the secondary battery **11** when the detected charging current Ichr is being feedback-controlled to the command learning current Ist. Based on the command learning current Ist and the learning temperature rise rate dTst, 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**.

After that, based on the difference between the limit temperature Tlimit and the initial temperature Tini of the secondary battery **11** and the determined period. TL, there is calculated a charging-time temperature rise rate dTf 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 dTf, the command learning current Ist and the learning temperature rise rate dTs are used for calculating the command charging current I*. Since the command learning current Ist and the learning temperature rise rate dTst 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 Ist and the learning temperature rise rate dTst in addition to the charging-time temperature rise rate dTf 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 Tlimit in the constant current charging phase.

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.

The determined amount of rise $\Delta T\alpha$ is divided by the learning period TA which has been required for the amount of temperature rise ΔTr to reach the determined amount of rise $\Delta T\alpha$ to thereby calculate a learning temperature rise rate dTs. According to this calculation method, the learning temperature rise rate dTst 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 dTst 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 S**41** is shortened more than in the situation where temperature rise is difficult, and accordingly the end of the learning phase comes earlier.

If the learning processing is determined to be inhibited at step S**11**, 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 Ist and the learning temperature rise rate dTst is lowered.

After the start of the constant current charging phase, if the temperature deviation Terr, which is the difference between the detected temperature Tbr and the estimated temperature Test, is equal to or larger than the threshold Tth, correction is performed to decrease the command charging current I*. If the temperature deviation Terr is equal to or smaller than −Tth, 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 Tlimit 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

The absolute value of the threshold (>0) used at step S**32** of FIG. **4** may be set to a value different from the absolute value of the threshold (<0) used at step S**35**.

Of the first to third conditions at step S**11** of FIG. **3**, any one or two of them may be used as conditions for determining whether to inhibit the learning processing.

The processing of step S**14** of FIG. **3** may be processing for calculating an amount of rise in detected temperature Tbr from the beginning of charging the secondary battery **11** at the command learning current Ist in the processing of step S**13** until the lapse of a predetermined period. In this case, the learning temperature rise rate dTst may be calculated, at step S**15**, by dividing the amount of rise in detected temperature Tbr by the predetermined period.

At step S**13** of FIG. **3**, the detected voltage Vbr may be used for calculating the command learning current Ist. Furthermore, SOC does not necessarily have to be used for calculating the command learning current Ist.

Second Embodiment

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.

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.

If an affirmative determination is made at step S**12**, control proceeds to step S**40**. At step S**40**, 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.

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**.

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 TA**1** to calculate a first learning temperature rise rate dTst1.

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 TL**1**. The first determined period TL**1** 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.

[Math. 4]

$$dTf1 = \frac{T_{limit} - T_{ini}1}{TL1} \tag{eq4}$$

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.

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**.

If an affirmative determination is made at step **S44**, control proceeds to step **S45** where a second learning period TA**2** 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 ΔT α is divided by the calculated second learning period TA**2** to calculate a second learning temperature rise rate dTst2.

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 TL**2**. In the present embodiment, the second determined period TL**2** is set to an assumed value corresponding to the duration of the constant current charging phase and smaller than the first determined period TL**1**.

[Math. 5]

$$dTf2 = \frac{T_{limit} - T_{ini}2}{TL2} \tag{eq5}$$

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**,

[Math. 6]

$$I1 *= I_{st}1\sqrt{\frac{dTf1}{dTst1}} \tag{eq6}$$

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**,

[Math. 7]

$$I2 *= I_{st}2\sqrt{\frac{dTf2}{dTst2}} \tag{eq7}$$

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.

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 12* 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.

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.

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.

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.

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*.

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

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**.

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. **6**A-**6**C of the first embodiment, and at time **t4**, the constant voltage charging phase is started.

Other Embodiments

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

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.

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

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.

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.

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.

[Math. 8]

$$P* = P_{st}\sqrt{\frac{dTf}{dTst}} \tag{eq8}$$

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**.

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

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.

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

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.

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.

What is claimed is:

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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