(19) **United States**

(12) **Patent Application Publication** (10) Pub. No.: **US 2020/0379050 A1**

IMANAKA et al. (43) **Pub. Date:** **Dec. 3, 2020**

(54) **MEASUREMENT APPARATUS, ENERGY STORAGE APPARATUS, MEASUREMENT SYSTEM, AND OFFSET ERROR MEASUREMENT METHOD**

(71) Applicant: **GS Yuasa International Ltd.**, Kyoto (JP)

(72) Inventors: **Yuki IMANAKA**, Kyoto (JP); **Seiji TAKAI**, Kyoto (JP); **Masayuki IMURA**, Kyoto (JP)

(57) **ABSTRACT**

A measurement device **50** of an electrochemical element **30** that is connected, via a first switch **40**, to a terminal part **22P** having a load connected thereto, wherein: the measurement device **50** is provided with a current limitation unit **75** provided to a bypass path BP of the first switch **40**, a current sensor **60** for measuring the current of the electrochemical element **30**, and a processing unit **100**; when a voltage difference ΔV between the voltage of the electrochemical element **30** and the voltage of the terminal part **22P** is equal to or greater than a prescribed value, the current limitation unit **75** permits the supply of power to the load through the bypass path BP, and when the voltage difference ΔV is less than the prescribed value, the current limitation unit **75** cuts off the current to the bypass path BP; and in a period of time after the first switch **40** has been turned off and until the voltage difference ΔV reaches the prescribed value due to a change in voltage of the terminal part **22P** because of discharging of a charge/discharge element **170** connected in parallel to the load, the processing unit **100** performs a measurement process to measure the offset error ε of the current sensor **60**.
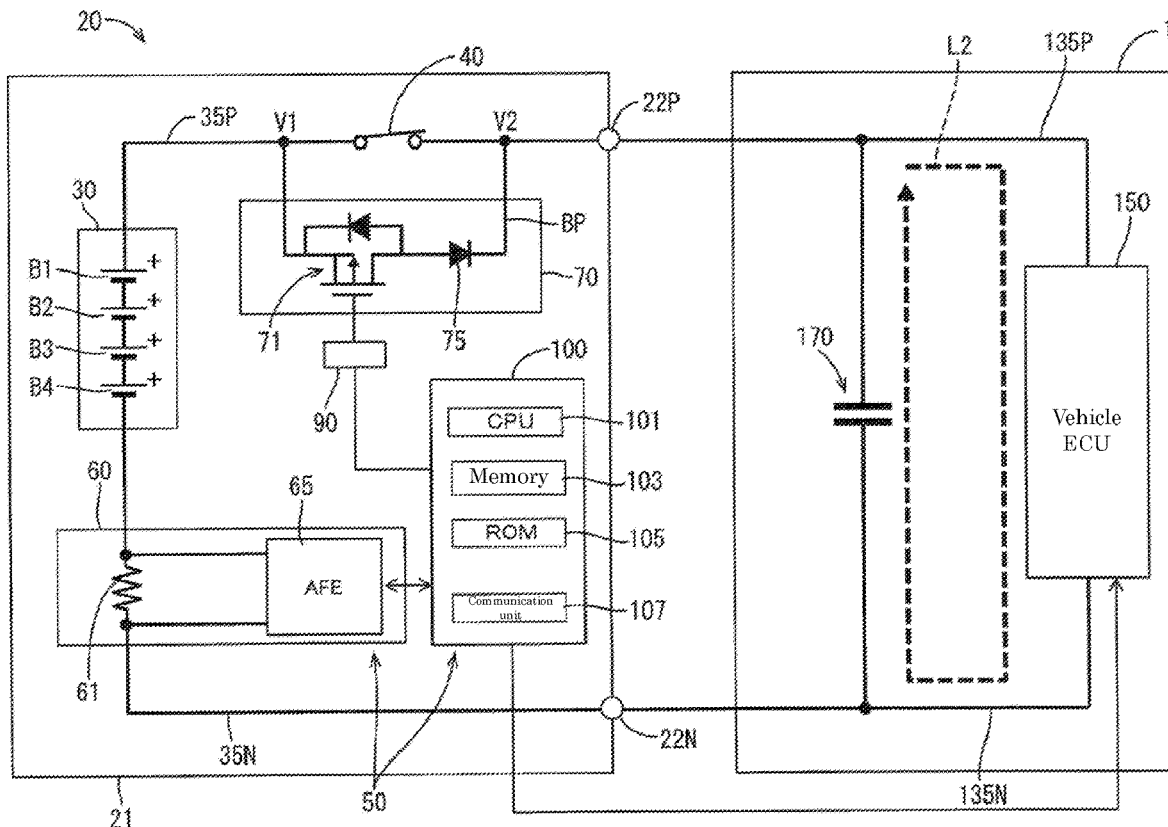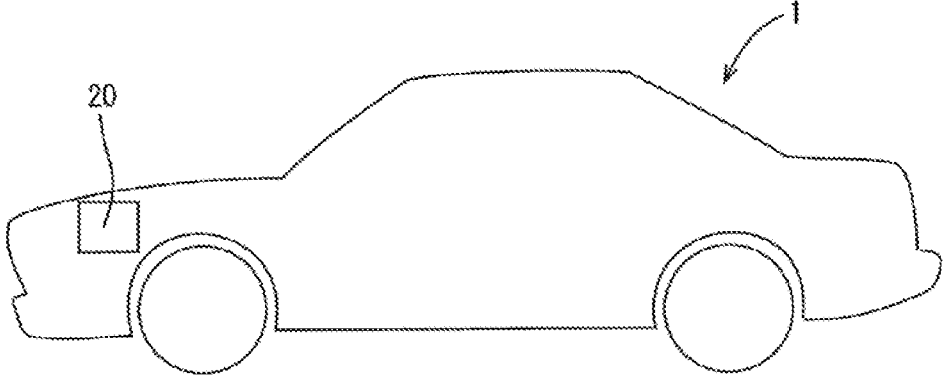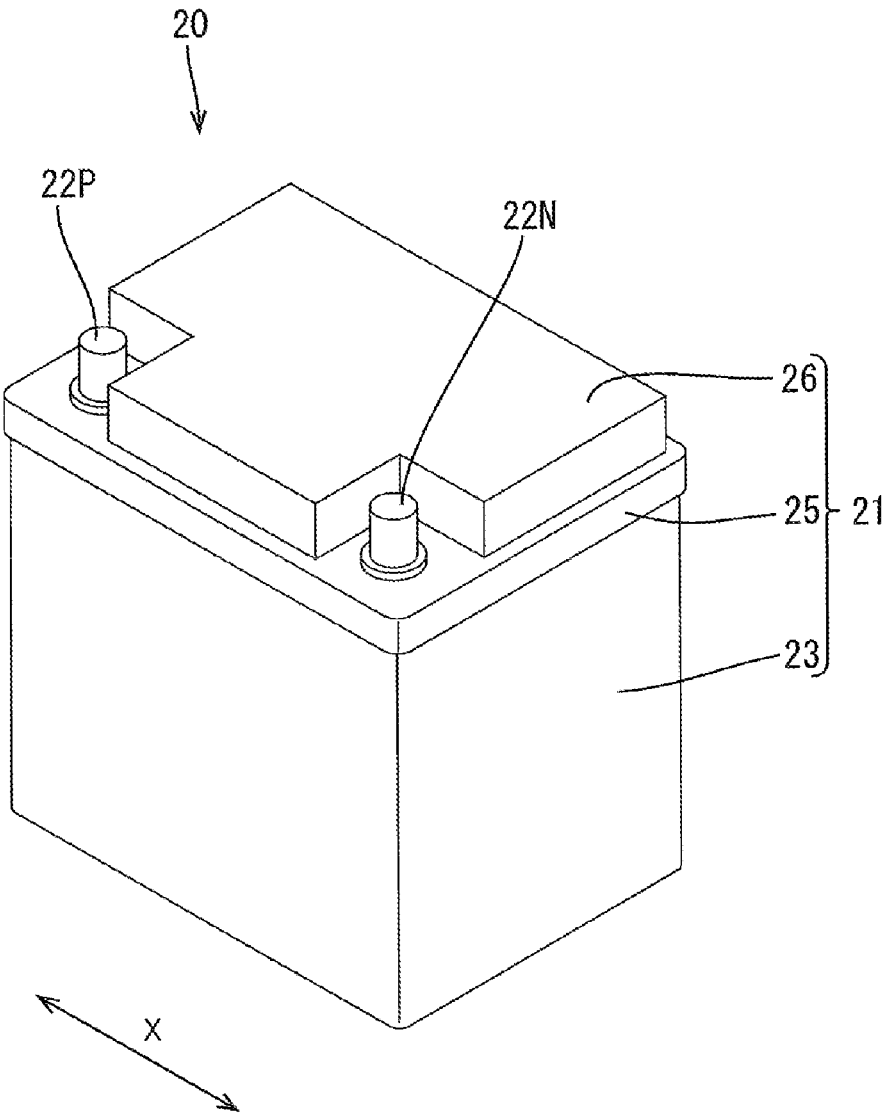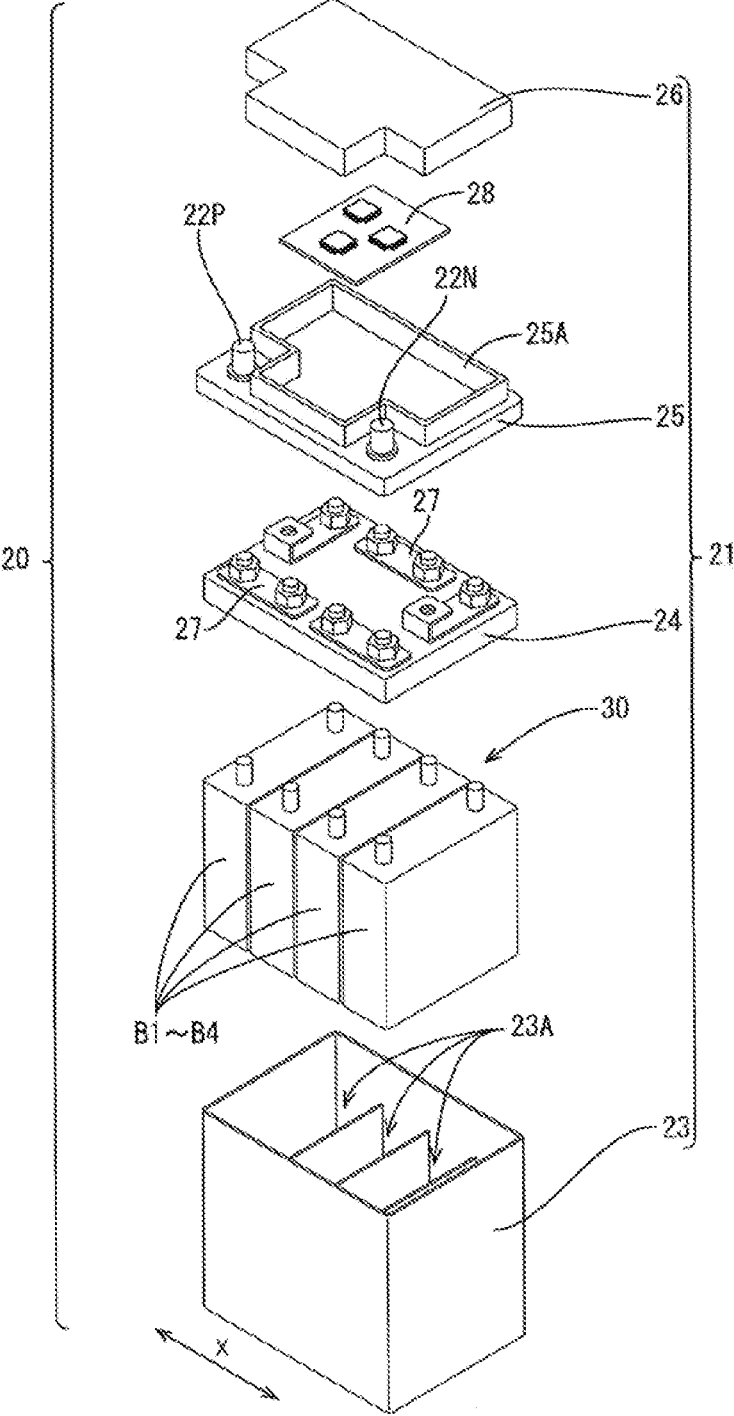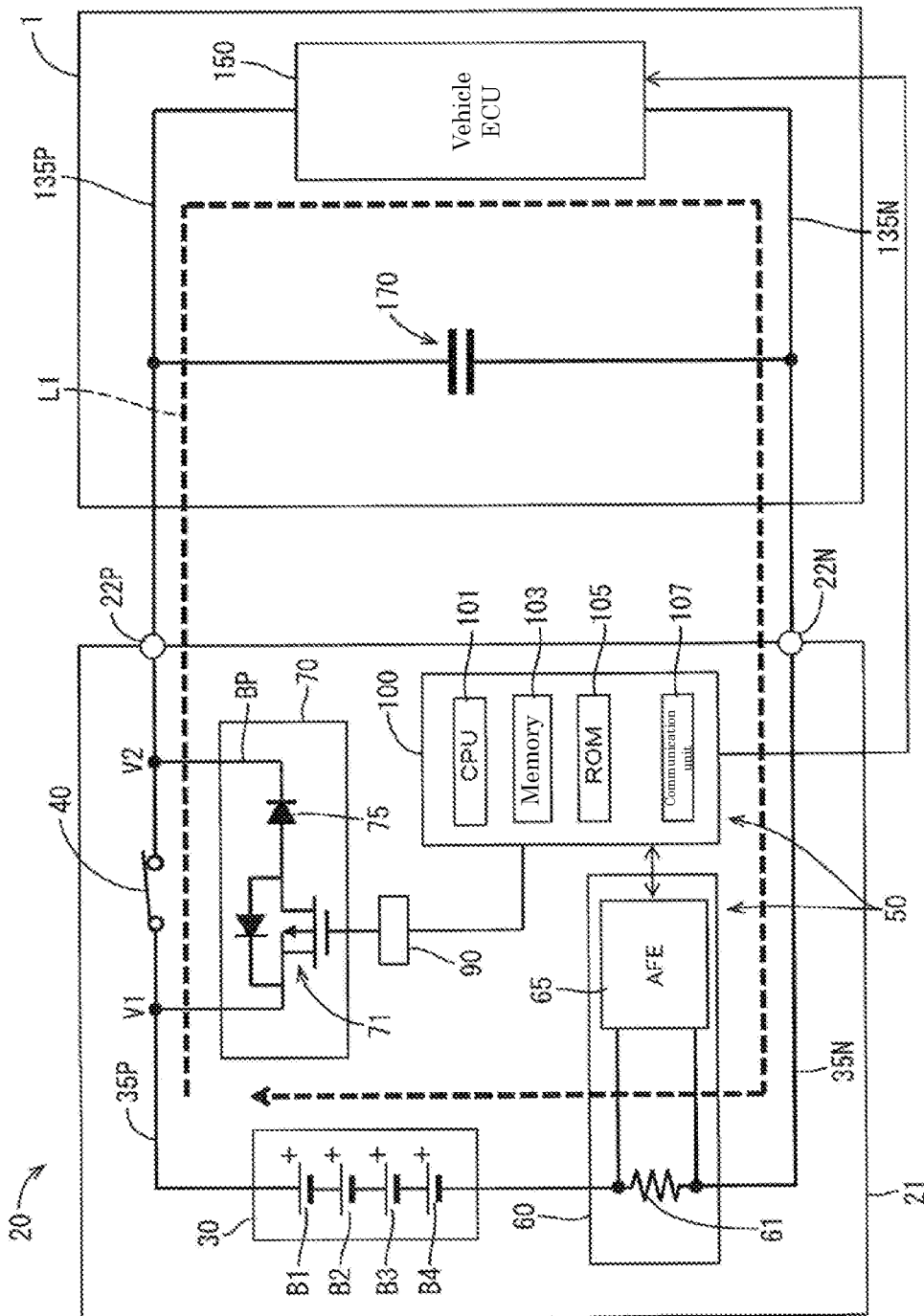
Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

```
                    ┌──────────────┐
                    │    Start     │
                    └──────┬───────┘
                           │
          ┌────────────────▼────────────────┐
          │                                 │◄──────────┐
          │        Is vehicle parked?       │   S10      │
          │                                 │──── NO ────┘
          └────────────────┬────────────────┘
                        YES │
                            │            S20
          ┌─────────────────▼─────────────────┐
          │  Switch second switch from off to on │
          └─────────────────┬─────────────────┘
                            │            S30
          ┌─────────────────▼─────────────────┐
          │    Switch first switch from on to off │
          └─────────────────┬─────────────────┘
                            │            S40
          ┌─────────────────▼─────────────────┐
          │     Measure and store offset error of │
          │            current sensor          │
          └─────────────────┬─────────────────┘
                            │            S50
          ┌─────────────────▼─────────────────┐
          │    Switch first switch from off to on │
          └─────────────────┬─────────────────┘
                            │            S60
          ┌─────────────────▼─────────────────┐
          │  Switch second switch from on to off │
          └─────────────────┬─────────────────┘
                            │
                    ┌───────▼──────┐
                    │     End      │
                    └──────────────┘
```
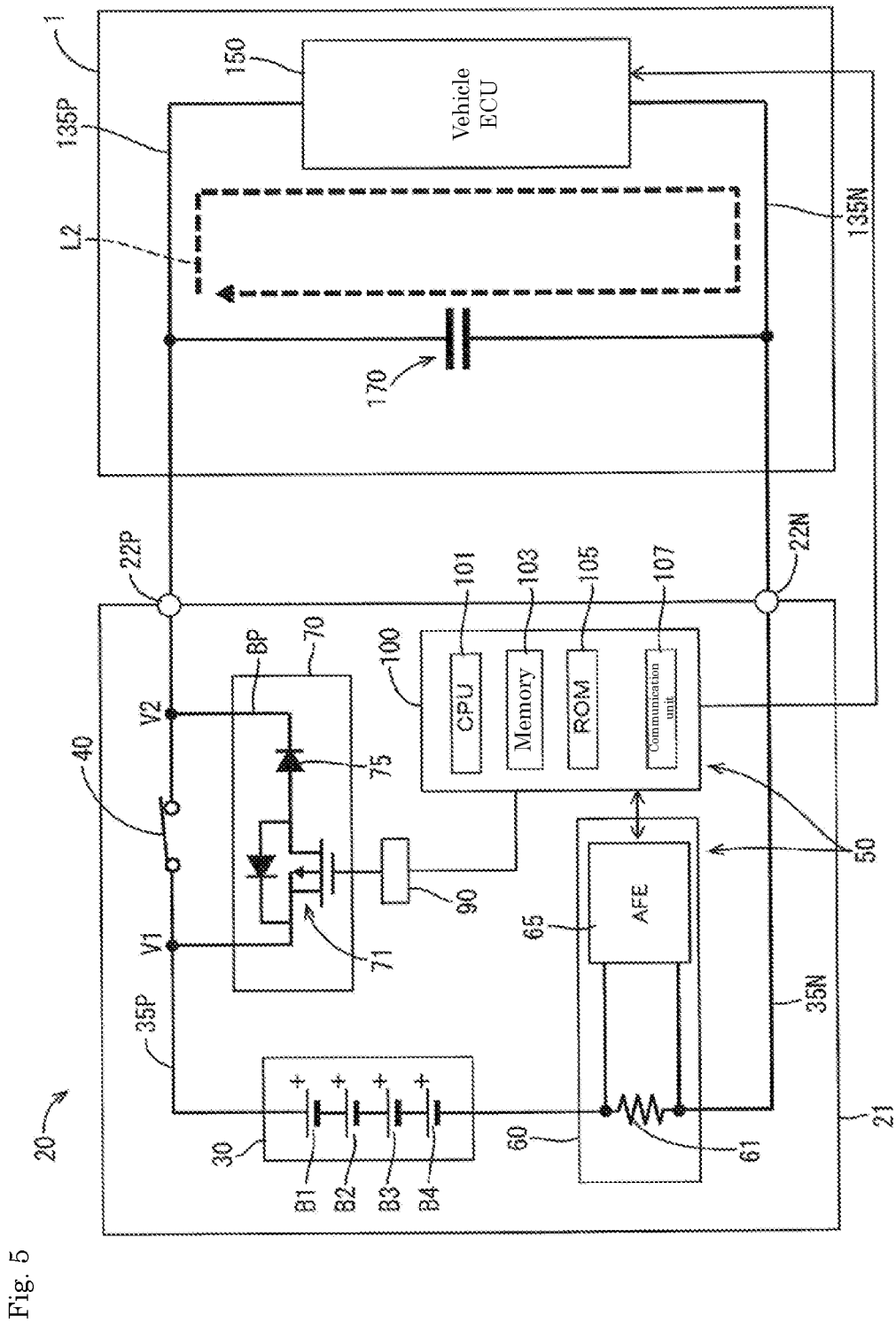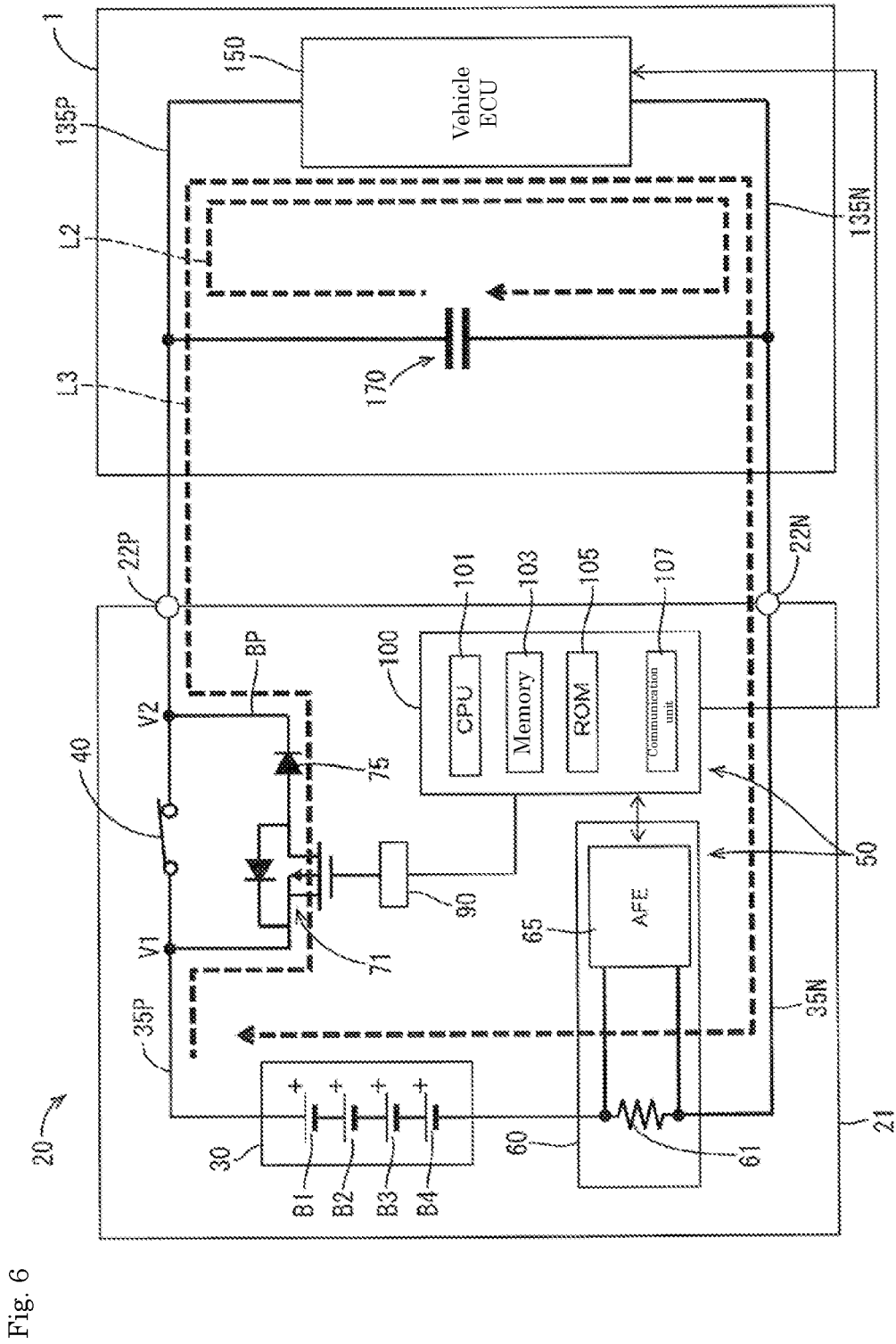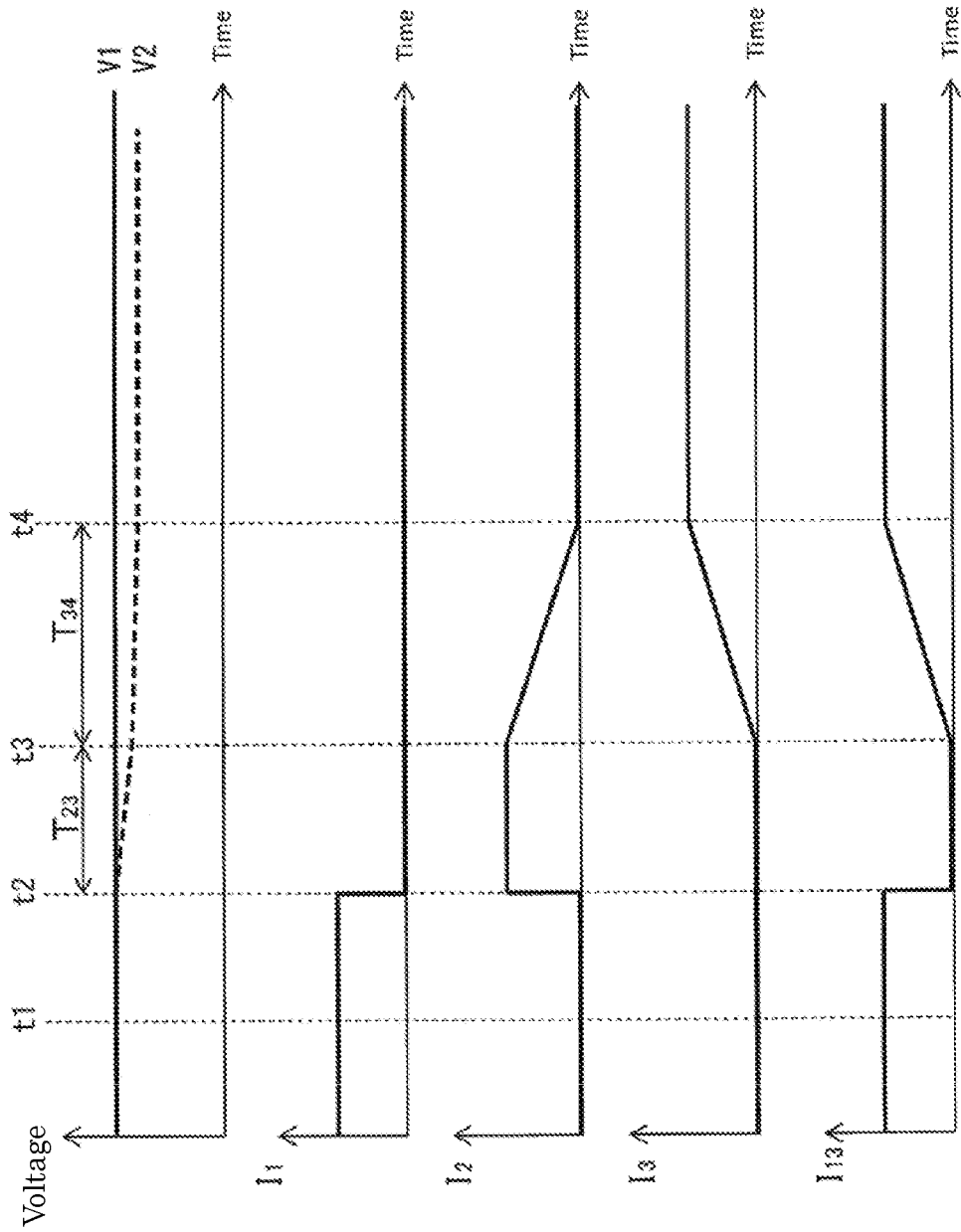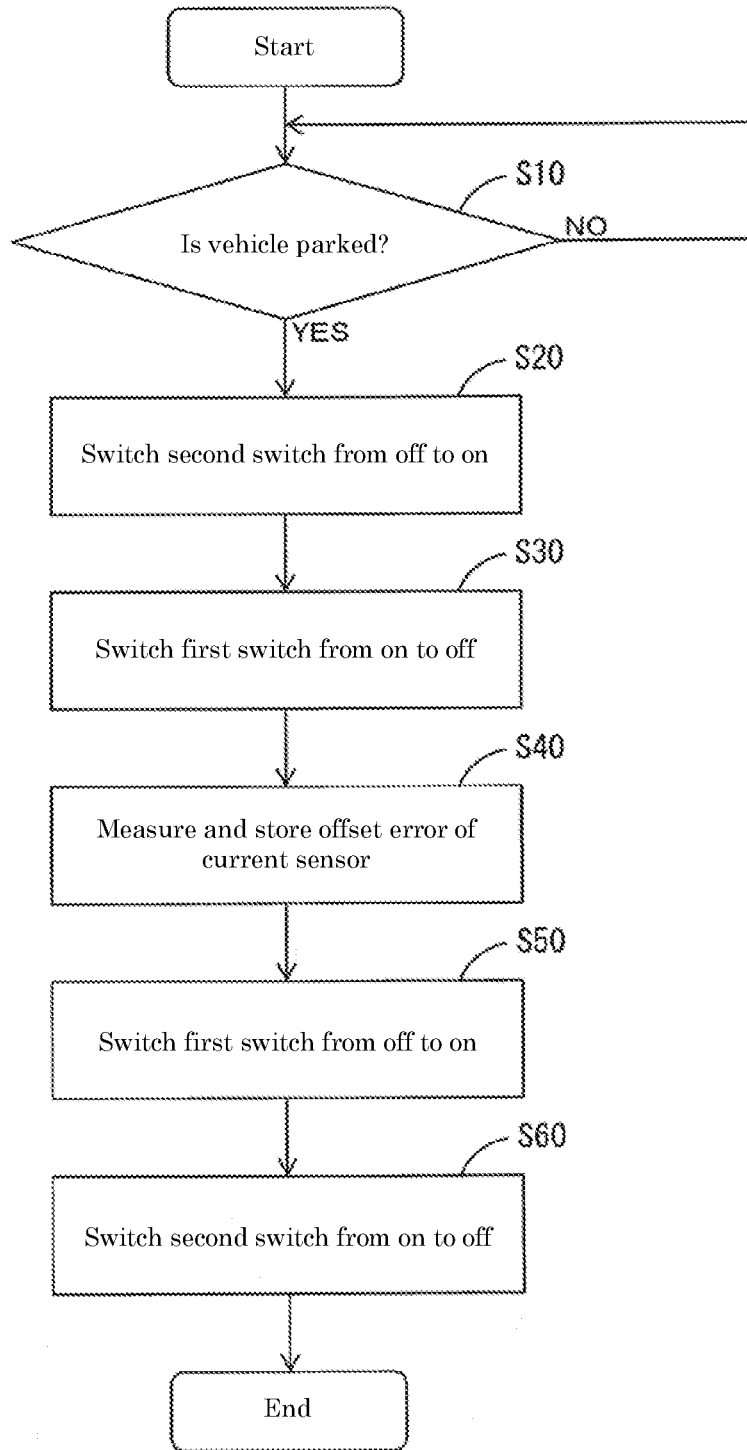
Fig. 11

Fig. 12

Fig. 13

Fig. 14

MEASUREMENT APPARATUS, ENERGY STORAGE APPARATUS, MEASUREMENT SYSTEM, AND OFFSET ERROR MEASUREMENT METHOD

CROSS REFERENCE TO RELATED APPLICATIONS
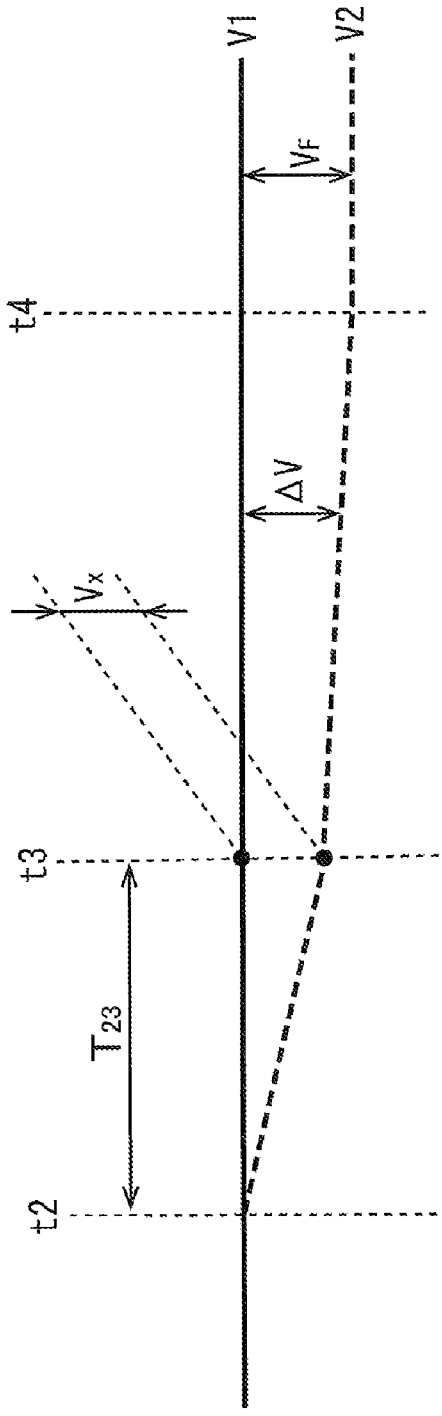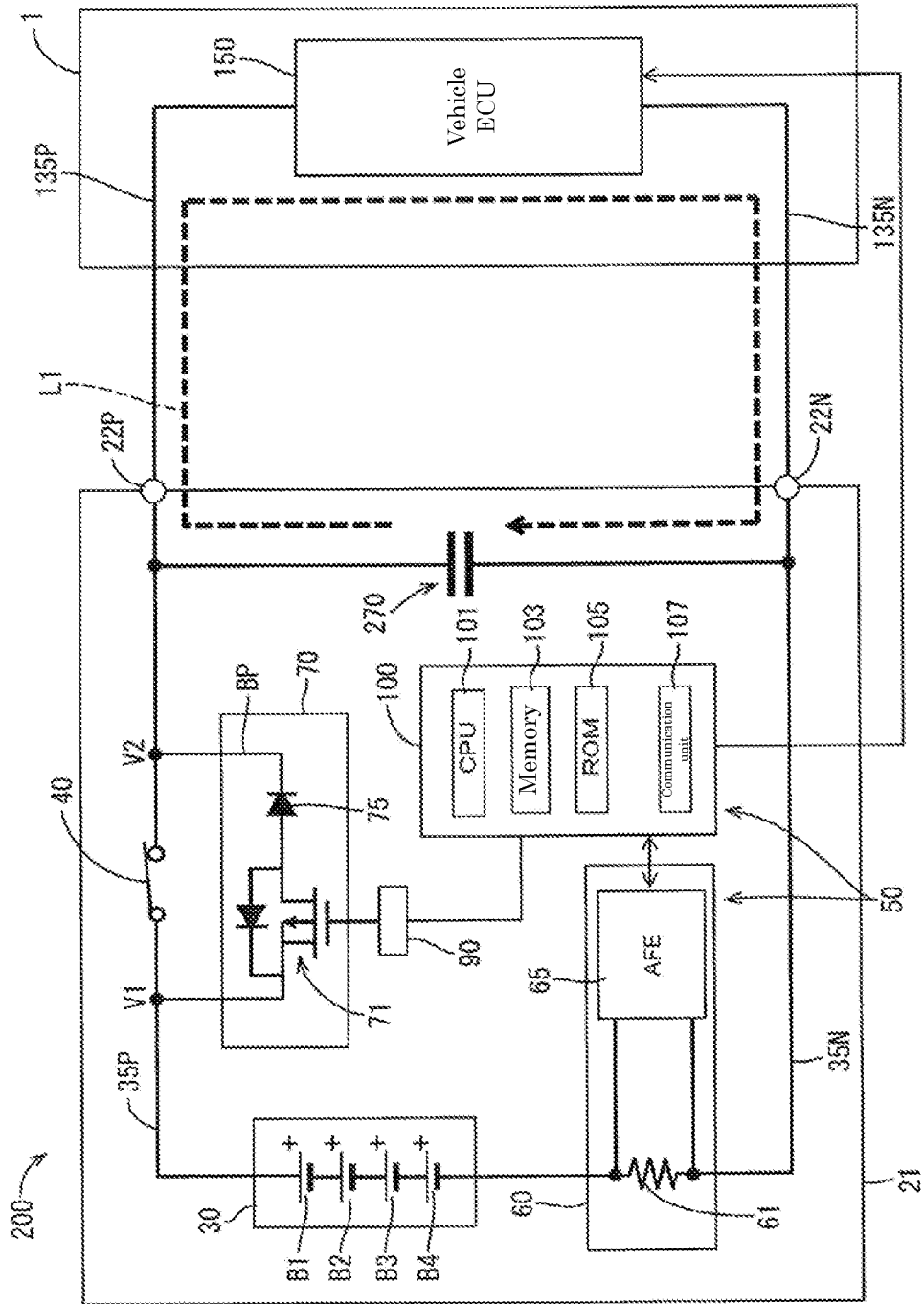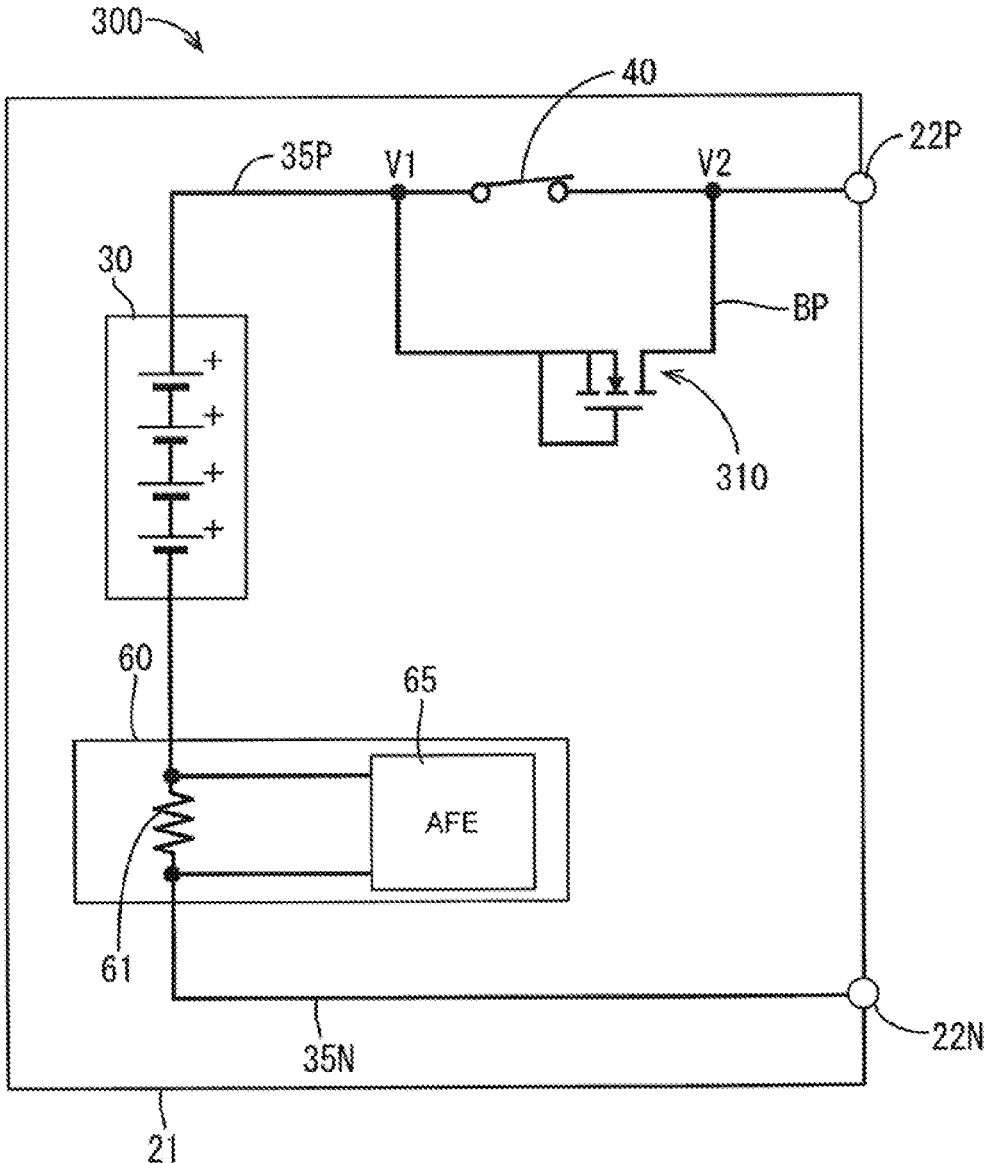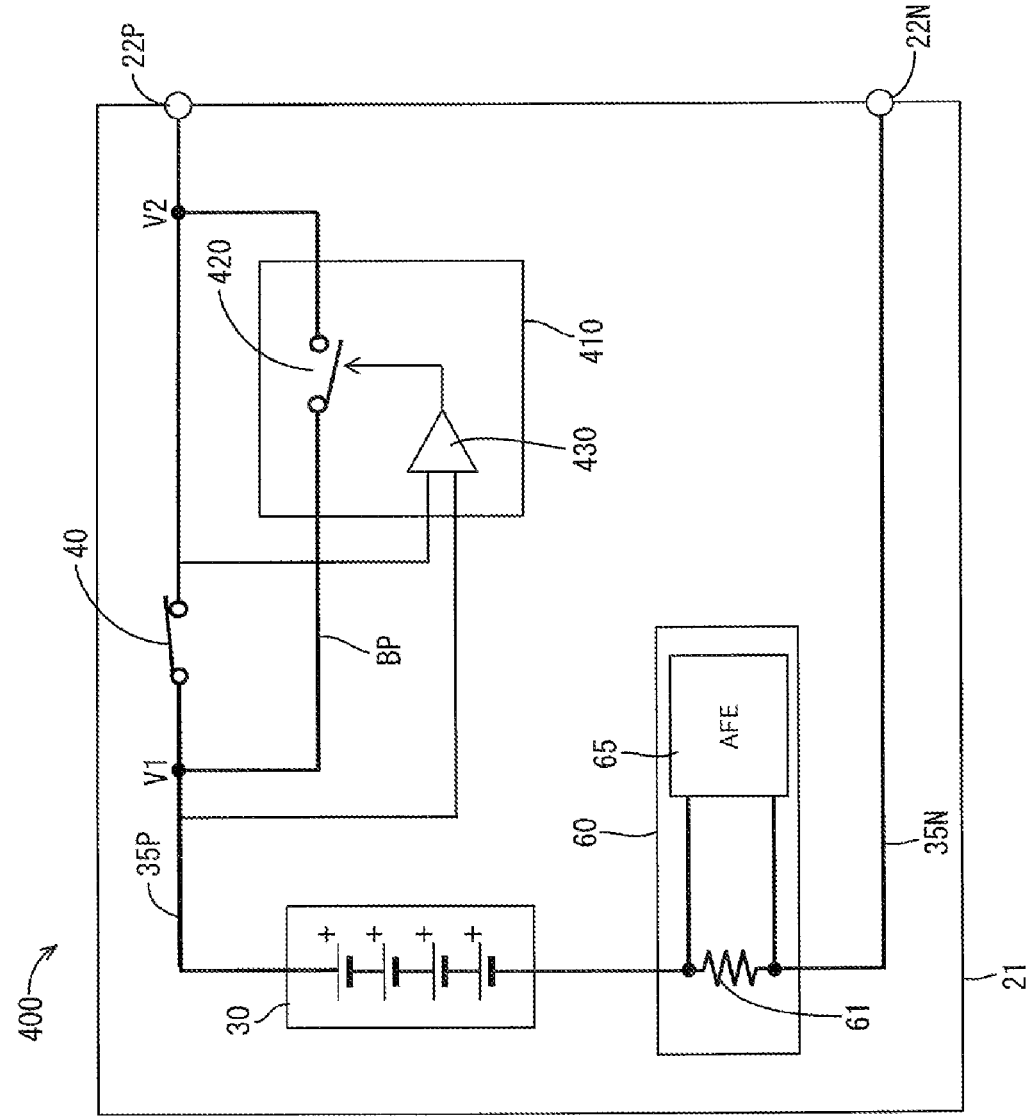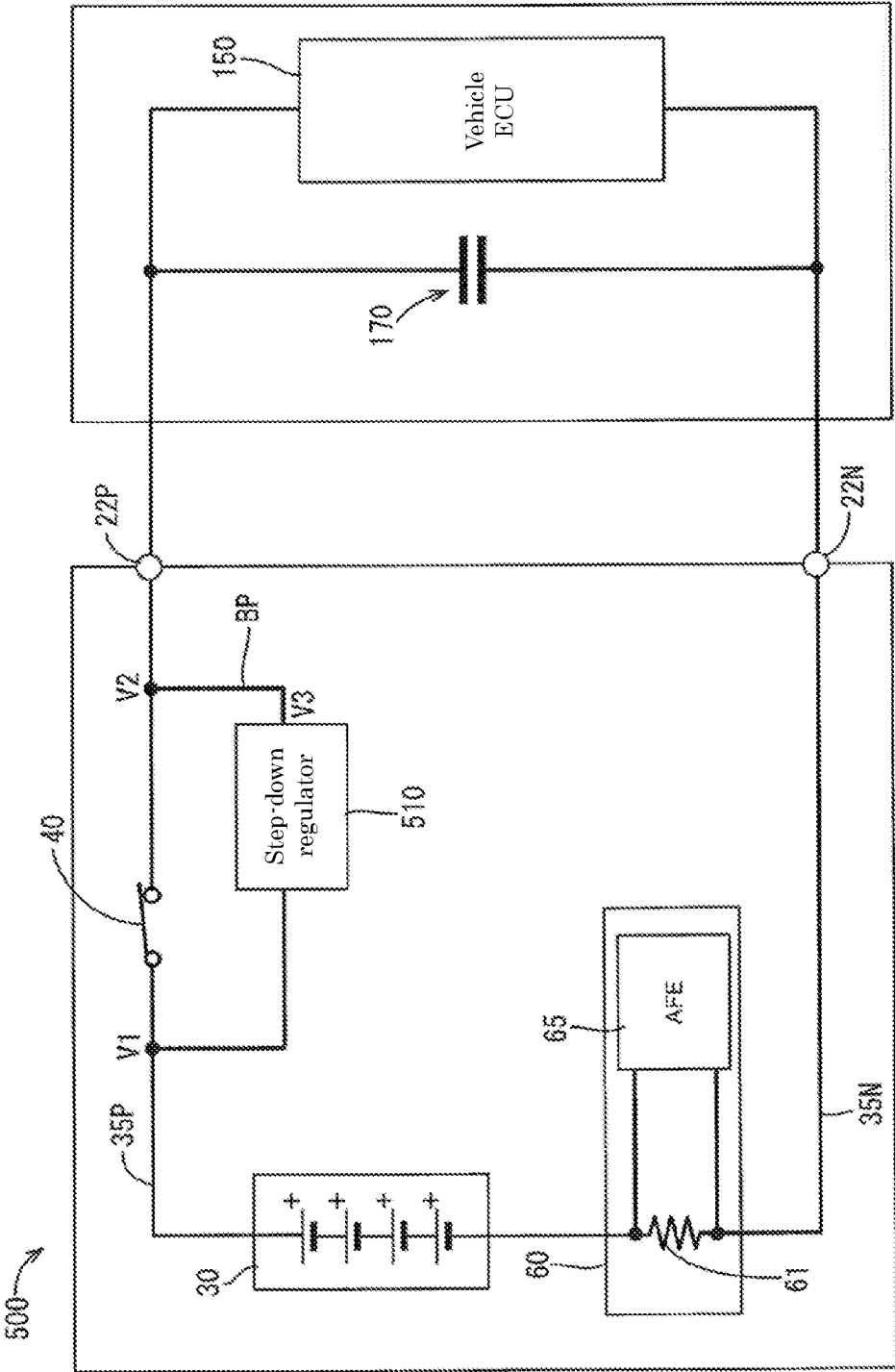
[0001] This application is a national stage application, filed under 35 U.S.C. § 371, of International Application No. PCT/JP2018/044505, filed Dec. 4, 2018, which international application claims priority to and the benefit of Japan Application No. 2017-232602, filed Dec. 4, 2017, the contents of both of which as are hereby incorporated by reference in their entireties.

BACKGROUND

Technical Field

[0002] The present invention relates to a technique for detecting the offset error of a current sensor.

Description of Related Art

[0003] The battery mounted in a vehicle estimates an SOC by integrating the current detected by a current sensor, as described in Patent Document JP-A-2017-83256.

BRIEF SUMMARY

[0004] A current sensor has an offset error indicating a numerical value other than zero even when the true value is zero. The offset error can be corrected by detecting the measurement value of the current sensor while the current is cut off. However, in order to measure the offset error, if the current is cut off, the power supply to the load is interrupted. The present invention has been completed based on the above circumstances, and has an object to measure the offset error of a current sensor while maintaining power supply to a load.

[0005] A measurement apparatus measures a current of an electrochemical device connected, via a first switch, to a terminal portion to which a load is connected. The apparatus includes a current limiting unit provided in a bypass path of the first switch, a current sensor configured to measure the current of the electrochemical device, and a processing unit. The current limiting unit allows power supply to the load through the bypass path when a voltage difference between a voltage of the electrochemical device and a voltage of the terminal portion is not less than a predetermined value, and makes the bypass path currentless when the voltage difference is less than the predetermined value. The processing unit performs measurement processing of measuring an offset error of the current sensor during a period until the voltage difference reaches the predetermined value due to a change in voltage of the terminal portion caused by discharging of a charge-discharge device connected in parallel with the load after the first switch is turned off.

[0006] The above technique can be applied to an energy storage apparatus, a measurement system, and an offset error measurement method. The techniques can be implemented in various forms such as offset error measurement programs and a recording medium recording the programs.

[0007] According to one aspect of the present invention, it is possible to measure an offset error while maintaining power supply to a load.

BRIEF DESCRIPTION OF THE FIGURES

[0008] FIG. 1 is a side view of an automobile according to the first embodiment.

[0009] FIG. 2 is a perspective view of a battery.

[0010] FIG. 3 is an exploded perspective view of a battery.

[0011] FIG. 4 is a block diagram showing the electrical configuration of the battery.

[0012] FIG. 5 is a diagram showing a current path to a vehicle ECU immediately after the first switch is turned off.

[0013] FIG. 6 is a diagram showing a current path to the vehicle ECU when the diode is conducting.

[0014] FIG. 7 is a diagram showing a current path to the vehicle ECU when the diode reaches the forward voltage.

[0015] FIG. 8 is a chart showing current and voltage waveforms.

[0016] FIG. 9 is an enlarged view of part of FIG. 8.

[0017] FIG. 10 is a flowchart showing an offset error measurement procedure.

[0018] FIG. 11 is a block diagram showing another embodiment of the battery.

[0019] FIG. 12 is a block diagram showing another embodiment of the battery.

[0020] FIG. 13 is a block diagram showing another embodiment of the battery.

[0021] FIG. 14 is a block diagram showing another embodiment of the battery.

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS

[0022] A measurement apparatus measures a current of an electrochemical device connected, via a first switch, to a terminal portion to which a load is connected. The apparatus includes a current limiting unit provided in a bypass path of the first switch, a current sensor configured to measure the current of the electrochemical device, and a processing unit. The current limiting unit allows power supply to the load through the bypass path when a voltage difference between a voltage of the electrochemical device and a voltage of the terminal portion is not less than a predetermined value, and makes the bypass path currentless when the voltage difference is less than the predetermined value. The processing unit performs measurement processing of measuring an offset error of the current sensor during a period until the voltage difference reaches the predetermined value due to a change in voltage of the terminal portion caused by discharging of a charge-discharge device connected in parallel with the load after the first switch is turned off.

[0023] In this configuration, when the first switch is switched from on to off, the main path becomes non-conductive and the current from the electrochemical device to the load is cut off. When the current from the electrochemical device is cut off, the charge-discharge device connected in parallel with the load is discharged, and the current flows through the load. When the charge-discharge device discharges, the voltage of the terminal portion changes. During the period until the voltage difference between the terminal portion and the electrochemical device reaches a predetermined value, the current limiting unit keeps the bypass path currentless. Therefore, the offset error of the current sensor can be detected during the period in which the bypass path is currentless. When the voltage difference from the energy storage device reaches a predetermined value, the current limiting unit permits power

supply to the load through the bypass path. Therefore, power can be supplied from the electrochemical device to the load through the bypass path.

[0024] In this configuration, even if the first switch is switched from on to off to cut off the main path, the power supply path from the electrochemical device to the load is not cut off because the bypass path is provided. Moreover, during an offset error measurement period, the bypass path becomes currentless, but the charge-discharge device discharges to the load. Therefore, it is possible to measure an offset error without causing power failure (power interruption to the load).

[0025] The electrochemical device is an energy storage device that supplies power to a vehicle load that does not allow power interruption, and the processing unit switches the first switch from on to off during parking of the vehicle and executes the measurement processing.

[0026] Vehicle loads highly relevant to the safety of the vehicle, such as the engine starter, the starting device for the EV drive system, the electronic control unit such as the vehicle ECU, and the auxiliary equipment for operating the drive unit (the engine or main drive motor for the EV), are required not to cause power failure not only while the vehicle is running or stopped but also while the vehicle is parked. That is, regardless of the state of the vehicle, it is required not to allow the power to be cut off (that is, to always be supplied with power). With this configuration, it is possible to measure an offset error of a vehicle load that does not allow such power interruption without causing power failure, and hence it is possible to meet the demand for ensuring safety.

[0027] In this configuration, an offset error is measured during parking, when the vehicle is less susceptible to a dangerous event than when the vehicle is running or stopped. Measuring an offset error during parking eliminates the necessity to measure an offset error while the vehicle is running or stopped, thereby securing high safety of the vehicle. In addition, the current flowing through the vehicle load is smaller during parking than during running or stopping. Therefore, a current limiting unit having a small rated capacity can be used.

[0028] The bypass path may be provided with a second switch in series with the current limiting unit. With this configuration, the bypass path can be cut off by turning off the second switch when no offset error is measured. Interrupting the current at the time of no measurement can prevent failure in the current limiting unit, and hence can improve the offset error measurement accuracy.

[0029] The current limiting unit is preferably a diode. A diode is suitable as a current limiting element because it switches between energization and deenergization depending on the voltage difference. It is possible to determine conduction or non-conduction by detecting the voltage difference across the diode, and it is possible to accurately measure an offset error by performing measurement processing during a non-conduction period.

First Embodiment

[0030] 1. Description of Battery

[0031] FIG. **1** is a side view of an automobile. FIG. **2** is a perspective view of a battery. FIG. **3** is an exploded perspective view of the battery. FIG. **4** is a block diagram showing the electric configuration of the battery.

[0032] The automobile **1**, which is a higher-level system, is an engine-driven vehicle equipped with an engine. As shown in FIG. **1**, the automobile **1** includes a battery **20** that is an energy storage apparatus. As shown in FIG. **2**, the battery **20** has a block-shaped battery case **21**. The battery case **21** accommodates an assembled battery **30** including a plurality of secondary batteries B1 to B4 and a circuit board **28**. The battery case **21** corresponds to the "container" according to the present invention.

[0033] As shown in FIG. **3**, the battery case **21** includes a box-shaped case main body **23** that opens upward, a positioning member **24** that positions the plurality of secondary batteries B1 to B4, and an inner lid **25** and an upper lid **26** which are mounted on the upper part of the case main body **23**. In the case main body **23**, as shown in FIG. **3**, a plurality of cell chambers **23**A for individually accommodating the respective secondary batteries B1 to B4 are provided side by side in the X direction.

[0034] As shown in FIG. **3**, the positioning member **24** has a plurality of bus bars **27** disposed on the upper surface. The positioning member **24** is disposed on the upper part of the plurality of secondary batteries B1 to B4 disposed in the case main body **23** so as to position the plurality of secondary batteries B1 to B4 and connect them in series via the plurality of bus bars **27**.

[0035] The inner lid **25** has a substantially rectangular shape in plan view, as shown in FIG. **2**. At both end portions of the inner lid **25** in the X direction, a pair of terminal portions **22**P and **22**N to which a harness terminal (not shown) is connected are provided. The pair of terminal portions **22**P and **22**N are made of, for example, a metal such as a lead alloy. The terminal portion **22**P is a positive electrode terminal portion and the terminal portion **22**N is a negative electrode terminal portion.

[0036] On the upper surface of the inner lid **25**, an accommodation portion **25**A is provided. The circuit board **28** is accommodated inside the accommodation portion **25**A of the inner lid **25**. When the inner lid **25** is attached to the case main body **23**, a secondary battery B and the circuit board **28** are connected. Further, the upper lid **26** is mounted on the upper part of the inner lid **25** so as to close the upper surface of the accommodation portion **25**A accommodating the circuit board **28**.

[0037] The electrical configuration of the battery **20** will be described with reference to FIG. **4**. The battery **20** is a 12-V system for a vehicle, and has an assembled battery **30**, a first switch **40**, and a measurement apparatus **50**.

[0038] The assembled battery **30** includes four lithium ion secondary batteries B1 to B4 connected in series. The lithium ion secondary batteries B1 to B4 each are an example of the "electrochemical device (energy storage device)" according to the present invention.

[0039] The positive electrode of the assembled battery **30** is connected to the positive electrode side terminal portion **22**P via the first switch **40**. The negative electrode of the assembled battery **30** is connected to the negative electrode side terminal portion **22**N via a current detection resistor **61**. Reference numeral **35**P denotes a positive electrode side energization path of the assembled battery **30**, and reference numeral **35**N denotes a negative electrode side energization path of the assembled battery **30**.

[0040] The first switch **40** is a switch that shuts off current to the assembled battery **30**, and can be formed from a relay,

a FET, or the like. The first switch **40** is arranged on the circuit board **28** and is accommodated in the battery case **21**.

[0041] The measurement apparatus **50** is the entire apparatus that measures the current of the assembled battery **30**, and includes a current sensor **60**, a parallel circuit **70**, and a processing unit **100**. The measurement apparatus **50** is arranged on or near the circuit board **28** and accommodated in the battery case **21**.

[0042] The current sensor **60** includes the current detection resistor **61** and an AFE (Analog Front End) **65**. The current detection resistor **61** is arranged in the energization path **35N** on the negative electrode side of the assembled battery **30** in the battery case **21**. The current detection resistor **61** is arranged on or near the circuit board **28**.

[0043] The AFE **65** detects the voltage across the current detection resistor **61** and changes the analog value to a digital value. The AFE **65** is connected to the processing unit **100** via a signal line. The AFE **60** is arranged on the circuit board **28**.

[0044] The parallel circuit **70** is on a bypass path BP of the first switch **40** and is connected in parallel with the first switch **40**. The parallel circuit **70** includes a second switch **71** and a diode **75**. The FET **71** and the diode **75** are connected in series. The parallel circuit **70** is provided on the circuit board **28**.

[0045] The second switch **71** is a P-channel field effect transistor whose source is connected to the positive electrode of the assembled battery **30** and whose drain is connected to the anode of the diode **75**. The forward direction of the diode **75** coincides with the discharging direction of the assembled battery **30**. The diode **75** has an anode connected to the drain of the second switch **71** and a cathode connected to the positive electrode side terminal portion **22P**. Reference numeral **90** shown in FIG. **4** denotes a drive circuit that drives the second switch **71**.

[0046] The processing unit **100** includes a CPU (central processing unit) **101** having a calculation function, a memory **103**, a ROM **105**, and a communication unit **107** and is arranged on the circuit board **28**.

[0047] The CPU **101** sends commands to the first switch **40** and the second switch **71** to ON/OFF-control the first switch **40** and the second switch **71**. "ON" means close (closed circuit), and "OFF" means open (open circuit).

[0048] The CPU **101** performs the process of detecting the current I of each of the lithium ion secondary batteries B1 to B4 based on an output from the AFE **65**, and the processing of estimating the SOC of each of the lithium ion secondary batteries B1 to B4 based on the detected current I.

[0049] An SOC (state of charge) is the ratio of the remaining capacity to the full charge capacity and is represented by equation (1) given below. An SOC can be estimated based on the integral value of the current I with respect to time as indicated by equation (2) given below. The sign of current is positive at the time of charging, and negative at the time of discharging.

$$SOC = Cr/Co \times 100 \qquad (1)$$

where Co is the full charge capacity of the secondary battery, and Cr is the remaining capacity of the secondary battery.

$$SOC = SOCo + 100 \times \int I dt / Co \qquad (2)$$

[0050] where SOCo is the initial value of the SOC, and I is the current.

[0051] The ROM **105** stores a program for estimating an SOC and a program for executing a measurement procedure

for an offset error ε (steps S**10** to S**60** shown in FIG. **10**). The program can be stored in a recording medium such as a CD-ROM and transferred. The program can also be distributed by using a telecommunication circuit.

[0052] The communication unit **107** is provided for communication with a vehicle ECU (Electronic Control Unit) **150** mounted in the automobile **1**. The vehicle ECU **150** is a vehicle load that does not allow power interruption regardless of the state of the vehicle such as a running state, stopping state, and parking state. After being mounted on the vehicle, the communication unit **107** is connected to the vehicle ECU **150** via a signal line, and the processing unit **100** can receive information about the vehicle such as the operating state (stopped or driven) of the engine from the vehicle ECU **150**.

[0053] As shown in FIG. **4**, the vehicle ECU **150** is connected to the battery **20** via power supply lines **135P** and **135N**, and power is supplied from the battery **20** to the vehicle ECU **150**. The vehicle ECU **150** is provided with a capacitor **170**. The capacitor **170** is provided between the power supply line **135P** on the positive electrode side and the power supply line **135N** on the negative electrode side, and is connected in parallel with the vehicle ECU **150**. The capacitor **170** is provided to stabilize the power supply voltage of the vehicle ECU **150**. The capacitor **170** plays a role of discharging and supplying power to the vehicle ECU **150** during a period in which the offset error ε of the current sensor **60** is measured. The capacitor **170** corresponds to the "charge-discharge device" according to the invention.

[0054] Because the battery **20** includes the lithium ion secondary batteries B1 to B4, the battery case **21** that accommodates the lithium ion secondary batteries B1 to B4, the first switch **40**, and the measurement apparatus **50**, and corresponds to the "energy storage apparatus" according to the present invention. The assembled battery **30** and the measurement apparatus **50** of the battery **20** correspond to the "measurement system" according to the present invention.

[0055] 2. Offset Error ε of Current Sensor **60** and Correction

[0056] The current sensor **60** has the offset error ε indicating a numerical value other than zero even when the true value is zero. The offset error ε can be measured by detecting the measurement value of the current sensor **60** (the output value from the AFE **65**) while a current I of the assembled battery **30** is cut off. However, in order to measure the offset error ε, if the current I is cut off, the power supply to the vehicle ECU **150** is interrupted.

[0057] In this configuration, the capacitor **170** discharges after the first switch **40** is turned off. Because discharging lowers the voltage of the capacitor **170**, a voltage V2 of the terminal portion **22P** drops. During a period T_{23} until a voltage difference ΔV between the voltage V2 of the terminal portion **22P** and a voltage V1 of the positive electrode of the assembled battery **30** reaches a predetermined value Vx, a diode **75** is non-conductive. The offset error ε of the current sensor **60** is measured by paying attention to the fact that the current I of the assembled battery **30** is cut off during the period T_{23} in which the diode **75** is non-conductive.

[0058] A method of measuring the offset error ε will be described below with reference to FIGS. **4** to **9**. First, the processing unit **100** controls the first switch **40** to be in the ON state and the second switch **71** to be in the OFF state in normal times (when the offset error ε is not measured). As

4

a result, as shown in FIG. **4**, a current flows from the assembled battery **30** to the vehicle ECU **150** through a main path L1 via the first switch **40**.

[0059] The capacitor **170** connected in parallel with the vehicle ECU **150** is charged, and the voltage V2 of the positive electrode side terminal portion **22P** of the battery **20** becomes equal to the positive electrode side voltage V1 of the assembled battery **30** (V2=V1).

[0060] When measuring the offset error ε, the processing unit **100** switches first the second switch **71** from off to on (at time t1 shown in FIG. **8**), and then switches the first switch **40** from on to off (at time t2 shown in FIG. **8**). The second switch **71** may be turned on at least when measuring the offset error ε, and may be always turned on.

[0061] "I$_1$" shown in FIG. **8** indicates a current flowing through the main path L1, "I$_2$" indicates a current discharged by the capacitor **170**, and "I$_3$" indicates a current flowing through the current path L3. "I$_{13}$" indicates the sum current of "I$_1$" and "I$_3$", and is the discharge current from the assembled battery **30** to the vehicle ECU **150**.

[0062] At time t2, when the first switch **40** switches from on to off, the main path L1 is cut off, and the capacitor **170** starts discharging. Therefore, a current flows from the capacitor **170** to the vehicle ECU **150** through the current path L2 shown in FIG. **5**. Because the voltage of the capacitor **170** drops due to discharging, as shown in FIGS. **8** and **9**, the voltage V2 of the positive electrode side terminal portion **22P** of the battery **20** drops and a voltage difference Δ occurs between the voltage V2 and the positive electrode side voltage V1 of the assembled battery **30** after the switching of the first switch **40**.

$$\Delta V = V1 - V2 \qquad (3)$$

[0063] At time t3 shown in FIGS. **8** and **9**, when the voltage difference Δ reaches the predetermined value V$_X$ (0.55 V as an example), the diode **75** is turned on. When the diode **75** is turned on, power is allowed to be supplied to the vehicle ECU **150** through the bypass path BP. As shown in FIG. **6**, a current flows to the vehicle ECU **150** through the current path L2 having the capacitor **170** as a power source and the current path L3 that passes from the assembled battery **30** to the parallel circuit **70** (bypass path BP).

[0064] After the diode **75** is turned on, the current flowing through the current path L3 increases and a current L2 flowing through the current path L2 decreases as the voltage difference ΔV increases. In the case shown in FIG. **8**, at time t4 when the voltage difference ΔV reaches the forward voltage Vf of the diode **75** (0.6 V as an example), the current in the current path L2 becomes zero. After that, power is supplied to the vehicle ECU **150** via the current path L3 passing through the diode **75**.

[0065] During the period T$_{23}$ from time t2 when the first switch **40** is turned off to time t3 when the diode **75** becomes conductive, the diode **75** is non-conductive and no current is output from the assembled battery **30**. Detecting the measurement value of the current sensor **60** (the output from the AFE **65**) during the period T$_{23}$ can measure the offset error ε of the current sensor **60**.

[0066] The diode **75** conducts to allow power to be supplied to the vehicle ECU **150** through the bypass path BP when the voltage difference ΔV is equal to or greater than the predetermined value Vx, and becomes non-conductive to make the bypass path BP currentless when the voltage difference ΔV is less than the predetermined value Vx.

Therefore, the diode **75** corresponds to the "current limiting unit" according to the present invention.

[0067] FIG. **10** is a flowchart showing an offset error ε measurement procedure. The measurement procedure is composed of six steps S10 to S60. Before execution of the measurement procedure, it is assumed that the CPU **101** performs control to turn on the first switch **40** and turn off the second switch **71**.

[0068] The CPU **101** determines first whether the vehicle **1** equipped with the battery **20** is parked (S10). The determination as to whether the vehicle is parked can be made based on the state of communication with the vehicle ECU **150**. That is, when the vehicle **1** is running or stopping, communication is frequently performed in a predetermined cycle between the vehicle ECU **150** and the processing unit **100**.

[0069] On the other hand, when the vehicle **1** is parked, the vehicle ECU **150** stops communication. Therefore, when communication with the vehicle ECU **100** is interrupted for a predetermined period, it can be determined that the vehicle **1** is parked.

[0070] Upon determining that the vehicle **1** is parked (S10: YES), the CPU **101** then switches the second switch **71** from off to on, and then performs the processing of switching the first switch **40** from on to off (S20, S30).

[0071] The CPU **101** then performs the measurement processing of measuring the offset error of the current sensor **60** during the period T$_{23}$ from the time when the first switch **40** is turned off to the time when the diode **75** becomes conductive, and stores the measured offset error ε in the memory **103** (S40). The length of the period T$_{23}$ can be obtained from the capacitance of the capacitor **170**, the discharge current of the capacitor **170**, the voltage difference Vx at which the diode **75** conducts, and the like. Experimental values can also be used.

[0072] Subsequently, the CPU **101** performs the processing of switching the first switch **40** from off to on, and then performs the processing for switching the second switch **71** from on to off (S50, S60). With the above, the offset error ε measurement procedure is completed.

[0073] The CPU **101** performs the correction processing of correcting the measurement value of the current sensor **60** by the offset error ε when measuring the current of each of the lithium ion secondary batteries B1 to B4, as indicated by equation (4) given below.

[0074] Performing this processing can improve the measurement accuracy of the current I and accurately estimate the SOCs of the lithium ion secondary batteries B1 to B4.

$$It = Io - \varepsilon \qquad (4)$$

[0075] where It is the current value after correction, Io is the current value before correction, and ε is the offset error. In equation (4), the signs of the current and offset error are positive in the charging direction and negative in the discharging direction.

[0076] Referring to FIG. **10**, the offset error ε is preferably updated to the latest value by repeatedly executing the offset error ε measurement procedure every predetermined period, for example, every one week. With this operation, even if the offset error ε changes due to a temperature change or the like, it is possible to reduce the influence of the change, and it is possible to further improve the measurement accuracy of the current I and the estimation accuracy of the SOC.

[0077] The parallel circuit **70** can be used as a diagnostic circuit for the close failure of the first switch **40**. That is, when the first switch **40** is switched from on to off with the second switch **71** of the parallel circuit **70** turned on, if the first switch **40** is operating normally, the voltage across the first switch **40**, that is, $\Delta V (=V1-V2)$, is the forward voltage VF of the diode **75**. On the other hand, when the first switch **40** is stuck in the closed state, the voltage ΔV across the both ends becomes zero. Therefore, detecting the voltage ΔV across the first switch **40** can diagnose whether the first switch **40** has a close failure.

[0078] 4. Description of Effect

[0079] In this configuration, even if the first switch **40** is switched from on to off to cut off the main path L1, the power supply path from the assembled battery **30** to the vehicle ECU **150** is not cut off because the bypass path BP is provided. Moreover, during the measurement period of the offset error c, the diode **75** in the bypass path BP becomes non-conductive, and the current I of the assembled battery **30** is temporarily cut off. However, during the period T_{23} in which the current I is cut off, if the capacitor **170** discharges to the vehicle ECU **150** and the diode **75** becomes conductive, then the current I can be supplied from the assembled battery **30** via the bypass path BP. Therefore, it is possible to measure the offset error ε while maintaining the power supply to the vehicle ECU **150** that does not allow power-off. With this configuration, it is possible to measure the offset error ε of a vehicle load that does not allow such power interruption without causing power failure, and hence it is possible to meet the need to ensure safety.

[0080] The processing unit **100** switches the first switch **40** from on to off and measures the offset error ε of the current sensor **60** during parking during which the vehicle **1** is less likely to fall into a dangerous situation than when the vehicle **1** is running or stopping. Measuring the offset error ε during parking eliminates the necessity to measure the offset error ε while the vehicle is running or stopping, so that high safety of the vehicle can be secured. Further, the current consumption of the vehicle ECU **150** is smaller than that when the vehicle is running or stopping, and the current flowing through the diode **75** when conducting is small. Therefore, the diode **75** having a small rated capacity can be used.

[0081] In this configuration, when the offset error ε is not measured (periods other than T_{23}), the CPU **101** performs control to turn off the second switch **71**. Turning off the second switch **71** can cut off the bypass path BP. Interrupting the current at the time of no measurement can prevent failure in the diode **75** as the current limiting unit, and hence can improve the accuracy of measurement of the offset error ε. Further, when the assembled battery **30** has an abnormality such as over discharge, the current flowing through the bypass path BP can be interrupted by turning off the second switch **71**.

Other Embodiments

[0082] The present invention is not limited to the embodiments described with reference to the above description and the drawings. For example, the following embodiments are also included in the technical scope of the present invention.

[0083] (1) The first embodiment has exemplified the measurement apparatus **50** that measures currents in the lithium ion secondary batteries B1 to B4. This technology can be widely applied to any electrochemical devices other than the lithium ion secondary batteries B1 to B4 as long as it is a measurement apparatus for measuring currents. The electrochemical device includes a secondary battery, an energy storage device such as an electric double layer capacitor, a primary battery that only discharges, a fuel cell, and a solar cell. Although the first embodiment has exemplified the configuration in which the plurality of lithium ion secondary batteries B1 to B4 are connected in series, a single cell configuration may be used.

[0084] (2) The first embodiment has exemplified the case in which the battery **20**, which is an energy storage apparatus, is mounted on an engine-driven vehicle. The use of the battery **20** is not limited to the engine-driven vehicle. The battery **20** may be mounted on an electric vehicle or a hybrid electric vehicle. This technology can be applied to energy storage apparatuses for aircraft, ships, and railways as well as for vehicles. In particular, the technology is preferably applied to a load that does not allow power interruption but may also be applied to a load that partially allow power interruption.

[0085] (3) Although the first embodiment has exemplified the configuration in which the assembled battery **30** supplies power to the vehicle ECU **150**, the power supply target (vehicle load) is not limited to the vehicle ECU **150**. The technology may be applied to other vehicle loads that do not allow power interruption, such as a starter motor for driving the engine and auxiliary machinery of the engine.

[0086] (4) The first embodiment has exemplified the case in which the first switch **40** and the parallel circuit **70** are provided on the positive electrode side of the assembled battery **30**, while the current sensor **60** is provided on the negative electrode side of the assembled battery **30**. The configuration may be reversed to provide the first switch **40** and the parallel circuit **70** on the negative electrode side of the assembled battery **30**, while providing the current sensor **60** on the positive electrode side of the assembled battery **30**. Assume that the first switch **40** and the parallel circuit **70** are provided at the negative electrode. In this case, when the first switch **40** is turned off, the voltage of the terminal portion **22N** changes due to the discharging of the capacitor **170**, and the voltage difference ΔV occurs between the negative electrode side terminal portion **22N** and the negative electrode of the assembled battery **30**. Until the generated voltage difference ΔV reaches the predetermined value Vx, the diode **75** is non-conductive. Accordingly, the offset error ε of the current sensor **60** can be measured during this period. When the first switch **40** and the parallel circuit **70** are provided on the negative electrode side, the voltage of the terminal portion **22N** becomes higher than that of the negative electrode of the assembled battery **30** due to the discharging of the capacitor **170**. Therefore, the anode and cathode of the diode **75** are respective connected to the terminal portion **22N** and the negative electrode of the assembled battery **30** so as to make the discharging direction coincide with the forward direction.

[0087] (5) The first embodiment has exemplified the capacitor **170** provided outside the battery. The capacitor **170** may be placed in the battery. The battery **200** shown in FIG. **11** includes the capacitor **270** inside the battery case **21**. One end of the capacitor **270** is connected to the positive electrode side terminal portion **22P**, and the other end is connected to the negative electrode side terminal portion **22N**. The capacitor **270** is charged by the assembled battery **30**. When the first switch **40** is turned off to cut off the main path L1, the capacitor **270** is discharged to supply power to

the vehicle ECU **150**. During the period T_{23} until the voltage difference ΔV between the voltage V1 of the positive electrode of the assembled battery **30** and the terminal portion V2 on the positive electrode side reaches the predetermined value Vx due to discharging from the capacitor **270**, the diode **75** is deenergized and the bypass path BP becomes currentless. Therefore, during the period T_{23}, the processing unit **100** can measure the offset error ε of the current sensor **60**. In this configuration, because the battery **20** incorporates the capacitor **270**, even if the capacitor **170** is not provided on the vehicle **1** side, the offset error ε of the current sensor **60** can be measured while power supply to the vehicle load **150** is continued. The capacitor **270** incorporated in the battery **20** plays a role of discharging to the vehicle load **150** during the period T_{23} in which the processing unit **100** measures the offset error ε.

[0088] (6) The capacitors **170** and **270** may be anything that discharges when the first switch **40** is turned off, and can be substituted by a charge-discharge device such as, for example, a secondary battery.

[0089] (7) The first embodiment has exemplified the diode **75** as a current limiting unit. The current limiting unit may be other than a diode, provided that the unit allows power supply to a load via the bypass path BP when the voltage difference ΔV between the voltage V1 of the assembled battery **30** and the voltage V2 of the terminal portion **22P** is equal to or greater than the predetermined value Vx, and makes the bypass path BP currentless when the voltage difference ΔV is less than the predetermined value. In the battery **300** shown in FIG. **12**, the current limiting unit is formed from the diode-connected FET **310**. The diode connection is to short-circuit the gate and the source. Like the diode **75**, the diode-connected FET **310** is conductive when the voltage difference is equal to or more than a predetermined value, and is non-conductive otherwise. This allows the FET **310** to substitute for the diode **75**. The battery **300** in FIG. **12** does not include the second switch **71**.

[0090] (8) In the battery **400** shown in FIG. **13**, the current limiting unit **410** includes a third switch **420** and a comparator **430**. The comparator **430** detects the voltage difference ΔV between the voltage V1 of the positive electrode of the assembled battery **30** and the voltage V2 of the positive terminal portion **22P**. The comparator **430** outputs a signal that turns on the third switch **420** when the voltage difference ΔV is equal to or larger than a predetermined value, and outputs a signal that turns off the third switch **420** when the voltage difference ΔV is less than the predetermined value. Even when the current limiting unit **410** is formed from the third switch **420** and the comparator **430**, the third switch **420** is turned off until the voltage difference ΔV reaches a predetermined value after the first switch **40** is turned off to make bypass path BP currentless. Accordingly, the offset error ε of the current sensor **60** can be measured during this period. Forming the current limiting unit **410** by using the third switch **420** and the comparator **430** provides the advantage of being able to arbitrarily set a threshold value (voltage difference) at which the bypass path BP switches from the non-energized state (third switch: off) to the energized state (third switch: on).

[0091] (9) A battery **500** shown in FIG. **14** uses a step-down regulator **510** as a current limiting unit. The step-down regulator **510** steps down the input voltage (the voltage V1 of the assembled battery) and outputs the resultant voltage.

The bypass path BP becomes currentless when the voltage V2 of the positive electrode side terminal portion **22P** is higher than an output voltage V3 of the step-down regulator **510**. Accordingly, after the first switch **40** is turned off, the offset error ε of the current sensor **60** can be measured during a period until the voltage V2 of the positive electrode side terminal portion decreases from the voltage V1 of the positive electrode of the assembled battery **30** to the output voltage V3 of the step-down regulator **510** due to the discharging of the capacitor **170**. When the voltage V2 of the terminal portion **22P** drops to the output voltage V3, the voltage V2 of the terminal portion **22P** is maintained afterward at the output voltage V3 of the step-down regulator **510**, and power can be supplied to the vehicle load **150** via the bypass path BP.

[0092] (10) In the first embodiment, the period T_{23} from the time when the first switch **40** is turned off to the time when the diode **75** becomes conductive is obtained from the capacitance of the capacitor **170**, the discharge current of the capacitor **170**, the voltage difference Vx at which the diode **75** conducts, and the like. The diode **75** is non-conductive when the voltage difference ΔV between the voltage V2 of the terminal portion **22P** and the voltage V1 of the positive electrode of the assembled battery **30** is smaller than the predetermined value Vx, and is conductive when the voltage difference reaches the predetermined value Vx. Therefore, after the first switch **40** is turned off, the voltage V2 of the terminal portion **22P** and the voltage V1 of the positive electrode of the assembled battery **30** are detected to obtain the voltage difference ΔV. The offset error ε may be measured during a period until the obtained voltage difference ΔV reaches the predetermined value Vx. This makes it possible to perform measurement during the period in which the diode **75** is deenergized, thereby improving the accuracy of measurement of the offset error ε. Even when the step-down regulator **510** is used for the current limiting section, it is possible to determine the currentless period of the bypass path BP by detecting the voltage V2 of the terminal portion **22P** and comparing it with the output voltage V3 from the step-down regulator.

[0093] (11) In the first embodiment, whether the vehicle **1** is parked is determined based on the state of communication with the vehicle ECU **150**, but it may be determined based on the magnitude of the current I of the assembled battery **30**. That is, it may be determined that the vehicle is parked when the current I is equal to or less than the predetermined value for a certain period of time. Alternatively, it may be determined from the presence or absence of vibration for a predetermined time or longer. It is advisable to detect vibrations with a sensor.

[0094] (12) In the first embodiment, the correction processing of correcting the current I of the lithium ion secondary batteries B1 to B4 is executed based on the offset error ε. Alternately, the SOC may be corrected without correcting the current I. Specifically, based on the integration time of the current I performed to calculate the SOC and the offset error c, the SOC error (the SOC error caused by the offset error ε of the current sensor **60**) may corrected.

[0095] (13) As long as the measurement apparatus **50** is constituted by the current sensor **60**, the parallel circuit **70**, and the processing unit **100**, the members **60**, **70**, and **80** need not necessarily be provided in the battery. The first embodiment has exemplified the configuration in which the first switch **40** and the parallel circuit **70** are provided inside

7

the battery **20**. The first switch **40** and the parallel circuit **70** may be provided outside the battery **20** as long as they are mounted on the vehicle. Similarly, the current sensor **60** and the processing unit **100** may be provided outside the battery **20** as long as they are mounted on the vehicle. That is, the battery **20** may be constituted by only lithium ion secondary batteries B1 to B4, the processing unit **100** provided outside the battery may measure the offset error ε by acquiring the data of the measurement value measured in the period T_{23} from the current sensor **60**.

[0096] (14) The measurement system may be any system that includes an electrochemical device such as the assembled battery **30** and the measurement apparatus **50** and measures a current in the electrochemical device **30** with the measurement apparatus **50**. The physical configuration may be any configuration, such as where the electrochemical device **30** and the measurement apparatus **50** are arranged.

[0097] (15) The technique disclosed in the first embodiment can be implemented in various forms such as offset error measurement programs for a current sensor and a recording medium recording the programs.

[0098] A measurement program for the offset error ε of the current sensor **60** causes the computer **40** to execute measurement processing (S**40**) of measuring the offset error ε of the current sensor **60** during the period T_{23} in which the current limiting device **75** makes the bypass path BP currentless after the first switch **40** connecting the terminal portion 22P and the electrochemical device **30** is turned off.

DESCRIPTION OF REFERENCE SIGNS

[0099] **1**: vehicle
[0100] **20**: battery (corresponding to "energy storage apparatus" according to present invention)
[0101] **30**: assembled battery
[0102] **40**: first switch
[0103] **60**: current sensor
[0104] **61**: current detection resistor
[0105] **65**: AFE
[0106] **70**: parallel circuit
[0107] **71**: second switch
[0108] **75**: diode (corresponding to "current limiting unit" according to present invention)
[0109] **100**: processing unit
[0110] **101**: CPU
[0111] **150**: vehicle ECU (corresponding to "vehicle load" according to present invention)
[0112] **170**: capacitor (corresponds to "charge-discharge device" according to present invention)
[0113] B1 to B4 . . . : lithium ion secondary battery (corresponding to "electrochemical device (energy storage device)" according to present invention)

1-9. (canceled)

10. A measurement apparatus for measuring a current of an electrochemical device connected, via a first switch, to a terminal portion to which a load is connected, the measurement apparatus comprising:
   a current limiting unit provided in a bypass path of the first switch;
   a current sensor configured to measure the current of the electrochemical device; and
   a processing unit,

wherein:
   the current limiting unit allows power supply to the load through the bypass path when a voltage difference between a voltage of the electrochemical device and a voltage of the terminal portion is not less than a predetermined value, and makes the bypass path current-less when the voltage difference is less than the predetermined value, and
   the processing unit performs measurement processing of measuring an offset error of the current sensor during a period until the voltage difference reaches the predetermined value due to a change in voltage of the terminal portion caused by discharging of a charge-discharge device connected in parallel with the load after the first switch is turned off.

11. The measurement apparatus according to claim **10**, wherein:
   the electrochemical device is an energy storage device configured to supply power to a vehicle load that does not allow power interruption, and
   the processing unit switches the first switch from on to off during parking of a vehicle and executes the measurement processing.

12. The measurement apparatus according to claim **10**, further comprising a second switch provided in the bypass path and connected in series with the current limiting unit.

13. The measurement apparatus according to claim **10**, wherein the current limiting unit is a diode.

14. An energy storage apparatus comprising:
   an energy storage device as an electrochemical device;
   a container configured to accommodate the energy storage device;
   a terminal portion which is provided in the container and to which a load is connected;
   a first switch accommodated in the container and provided between the energy storage device and the terminal portion; and
   the measurement apparatus according to claim **10**, which is accommodated in the container.

15. The energy storage apparatus according to claim **14**, further comprising a charge-discharge device accommodated in the container and connected to the terminal portion.

16. The energy storage apparatus according to claim **15**, wherein
   the energy storage apparatus is for a vehicle, and
   the charge-discharge device discharges, during a period in which the processing unit performs the measurement processing, to a vehicle load that does not allow power interruption.

17. A measurement system comprising:
   an electrochemical device; and
   the measurement apparatus according to claim **10**.

18. A method for measuring an offset error of a current sensor, the method comprising:
   turning off a first switch connecting a terminal portion and an electrochemical device and then discharging from a charge-discharge device connected in parallel with a load connected to the terminal portion; and
   causing a current limiting unit provided in the bypass path to make the bypass path current-less and measuring an offset error of the current sensor during a period until a voltage difference between a voltage of the energy storage device and a voltage of the terminal portion reaches a predetermined value.

* * * * *