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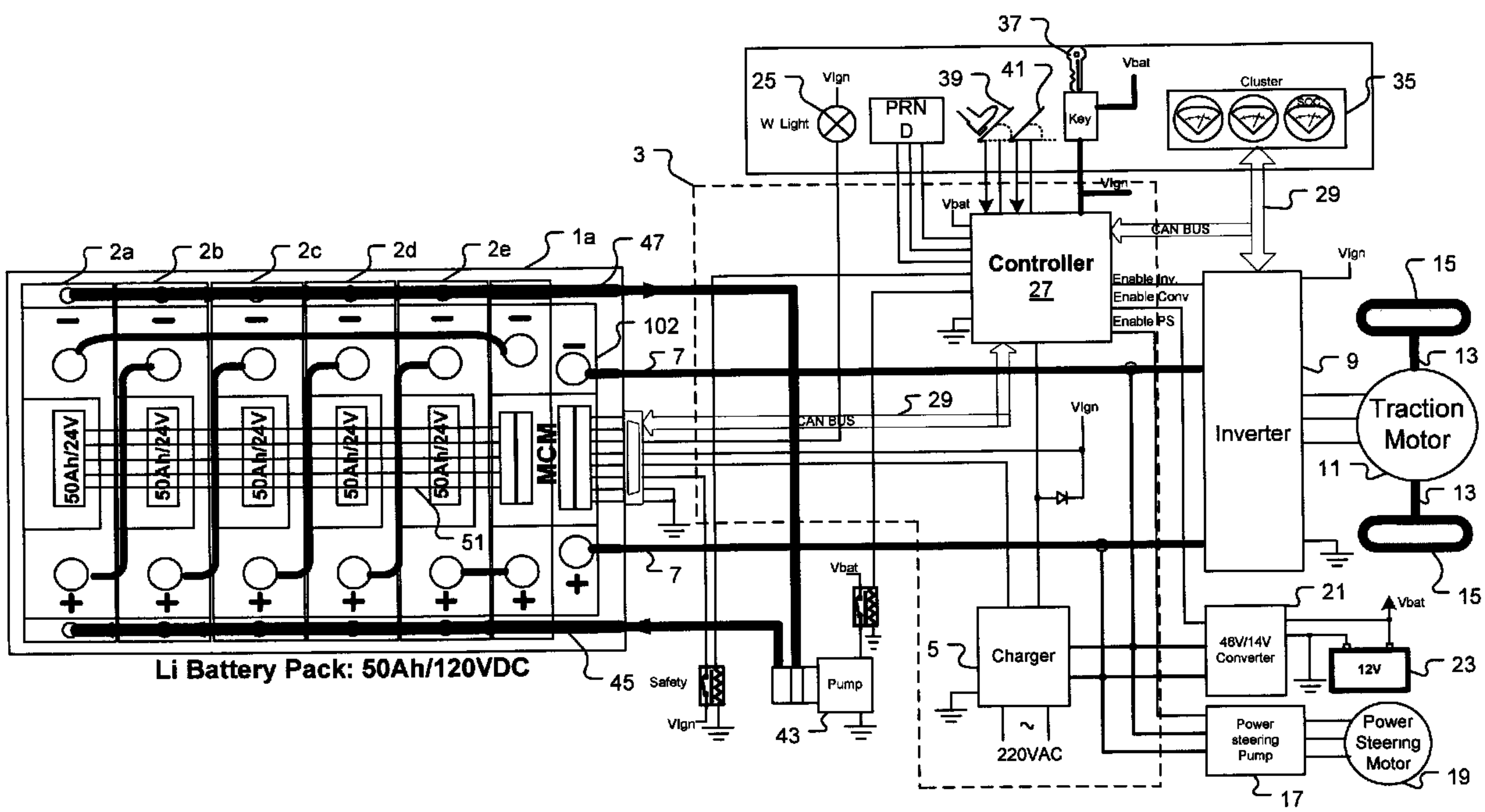

(57) Abrégé/Abstract:
A battery pack is provided including universal battery modules and a master control module. By selecting proper rated universal battery modules and connecting them either in series and/or parallel, a high performance and long life battery pack is assembled that is suitable for high power applications such as electrical vehicles whereby the master control module acts as the battery pack control and interface module.

ABSTRACT

[0001] A battery pack is provided including universal battery modules and a master control module. By selecting proper rated universal battery modules and connecting them either in series and/or parallel, a high performance and long life battery pack is assembled that is suitable for high power applications such as electrical vehicles whereby the master control module acts as the battery pack control and interface module.

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UNIVERSAL BATTERY MODULE AND CONTROLLER THEREFOR

FIELD OF THE INVENTION

[0002] The present invention pertains to energy storage devices, and more particularly, to battery modules and controller therefor.

BACKGROUND

[0003] With the advent of high power, high performance electric drive technology, transportation vehicles are increasingly being moved from the combustion engine platform to electric propulsion systems. Not only electric vehicles are more power efficient and robust due to their lesser number of internal components, but also they produce little or no environmentally harmful emissions associated with the ignition of fossil fuels in combustion engines.

[0004] High power battery packs are the key components for the successful implementation of electric drive technology in transportation vehicles. The battery pack is the main source of power for the pure electric propulsion system and comprises a plurality of series or parallel-connected cells. Initially, battery packs including a number of acid-lead cells were employed. The acid-lead cells were electrically coupled in series to one another to provide sufficient power for the electrical drive mechanism of the early electric vehicles. However, these early battery packs were quite bulky and heavy, and a short life cycle. Moreover, the acid-lead battery packs had a short cycle life, long charge time, and did not provide sufficient battery power over a long range.

[0005] In order to overcome some of these limitations, the manufacturers of battery packs have realized that batteries using the nickel-metal hydride cells or lithium-ion cells were lighter and less bulky, with a longer cycle life, faster charging and provided higher output power for longer distances. Accordingly, the nickel-metal hydride or lithium-ion battery packs have become the storage media of choice for high power applications such as electric drive vehicles.

[0006] In spite of the enormous success of the nickel-metal hydride battery packs, these devices suffer from the drawback that they are typically custom-designed for a specific application, having regard to the mechanical, thermal and electrical design constraints that are specific to the application. As a result, these battery packs are not interchangeable and cannot be readily integrated in other vehicles or high power applications.

[0007] Another major drawback of the existing battery packs is that the service life of the battery pack is typically shorter than other components of the vehicle. Due to high current drainage and high thermal operating conditions, it is not uncommon for the battery pack to fail and be replaced. The vehicle system controller is a component separate from the battery pack itself and outlasts the battery pack. As a result, every time a battery pack is replaced, the vehicle system controller must be calibrated or even replaced so as to correspond with the specifications of the new battery pack. Moreover, although the failure of the battery pack may be due to non-ideal performance or breakdown of one or a few individual battery cells within the battery pack, often the entire battery pack is to be replaced, as it is not possible to diagnose and manage the battery cells individually during operation.

[0008] This background information is provided to reveal information believed by the applicant to be of possible relevance to the present invention. No admission is necessarily intended, nor should be construed, that any of the preceding information constitutes prior art against the present invention.

SUMMARY OF THE INVENTION

[0009] An object of the present invention is to provide a universal battery module that can be easily integrated and used as standard building blocks for battery packs of various sizes and for various applications, such as electric vehicles, wind or solar energy storage devices, or telecommunication equipment.

[0010] It is a further object of this invention to provide battery modules with high volume production that are suitable for building battery packs of high performance and long life.

[0011] It is yet another object of the present invention to provide a master control module for power management of the universal battery modules in a battery pack.

[0012] The present invention arises from the realization that conventional battery packs used for high power applications such as electric vehicles are designed with the characteristics of the initial load consideration in mind. As a result, if the load capacity is varied or increased, the entire battery pack needs to be redesigned, reconfigured, or replaced to address the power, thermal and mechanical requirements of the new load. The present invention seeks to alleviate the shortcomings of existing batter packs by providing a flexible modular power storage platform that allows for interchangeability and expandability. The present invention provides a battery pack comprising a plurality of universal battery modules that are each configurable to be thermally, electrically, and mechanically coupled with the other universal battery modules in the battery pack in a modular fashion. The battery pack of the present invention can optionally include a controller to monitor the thermal and electrical characteristics of the unit, as well as to regulate and balance the power output of the universal battery modules in accordance with design and operation parameters.

[0013] The battery module of the present invention provides for a scalable and easily expandable battery system. The proposed modular design provides for sharing of power and cooling facilities, thus reducing production cost and simplifying manufacturing and reliability. In addition, a great reduction in vehicle inventory could be achieved if a single, reconfigurable battery module were able to provide equivalent functionality.

[0014] In a first aspect, the present invention provides a universal battery module having a plurality of series connected battery cells, sensor means coupled to the cells, the sensor means configured to transmit physical parameters of the cells, and a battery control unit in communication with the sensor means to control the cells based on physical parameters from the sensor means, wherein the battery control unit, the sensor means and the cells are packaged together as a single integral module.

[0015] In another aspect, the present invention provides a battery pack including at least two universal battery modules in a string of connected universal battery modules, each universal battery module including a plurality of series connected battery cells, sensor means coupled to the cells and configured to monitor and transmit physical parameters of the cells, a battery control unit in communication with the sensor means to control the cells based on physical parameters from the sensor means, and a master control module coupled to the string of universal battery modules, the master control module configured to control the battery pack power on/off and including internal electrical connector means to interface with each universal battery modules and control means to control electric equalization of the string of universal battery modules, wherein the string of universal battery modules and the master control module are packaged together as a single integral battery pack.

[0016] Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE FIGURES

[0017] A better understanding of these and other embodiments of the present invention can be obtained with reference to the following drawings which show by way of example embodiments of the present invention, in which:

[0018] FIG. 1(a) is a block diagram showing the components of an electric vehicle including a battery pack having a plurality of UBMs controlled by a MCM according to an embodiment of the present invention;

[0019] FIG. 1(b) is a block diagram showing the components of an electric vehicle including a battery pack having a plurality of UBMs according to another embodiment of the present invention;

[0020] FIG. 2 is a perspective view of a UBM according to an exemplary embodiment of the present invention;

[0021] FIG. 3 is a flow diagram indicating the steps involved in equalization and charging of cells in the UBM;

[0022] FIG. 4 is a perspective view of a MCM according to an exemplary embodiment of the present invention;

[0023] FIG. 5 is a flow diagram indicating the steps involved start-up operation of the MCM;

[0024] FIG. 6 is a flow diagram showing the steps in the start-up operation of the UBM;

[0025] FIG. 7 a state diagram illustrating various modes of operation of the UBM;

[0026] FIG. 8 a state diagram illustrating various modes of operation of the MCM;

[0027] FIG. 9 is a top schematic view of a battery pack having two UBMs that are electrically coupled in series with a MCM;

[0028] FIG. 10 is a top schematic view of a battery pack having four UBMs that are electrically coupled in series with no MCM; and

[0029] FIG. 11 is a top schematic view of a battery pack that includes an array of UBMs, wherein two rows of four UBMs are positioned side-by-side.

DETAILED DESCRIPTION OF THE INVENTION

Definitions

[0030] The term "sensor" is used to define a device having a measurable sensor parameter in response to a characteristic of a measurand, such as temperature, voltage or current.

[0031] The term "controller" is used to define a microcontroller having a programmable central processing unit (CPU) and peripheral input/output devices (such as A/D or D/A converters) to monitor parameters from sensors or other devices that are electrically coupled to the controller. These input/output devices can also permit the central processing unit of controller to communicate and control the devices coupled to the controller. The controller includes one or more storage media collectively referred to herein as "memory." The memory can be volatile and non-volatile computer memory such as RAM, PROM, EPROM, EEPROM, memory disks, or the like, wherein control programs (such as software, microcode or firmware) for monitoring or controlling the devices coupled to the controller are stored and executed by the CPU. Optionally, the controller also provides the means of converting user-specified operating requirements into control signal to control the peripheral devices coupled to the controller, whereby the controller is configured to receive user-specified commands by way of a user interface such as a keyboard or a graphical user interface (GUI).

[0032] The term Control Area Network (CAN) bus is used to define a serial data bus for reliable and high-speed communication of control signals.

[0033] The term battery equalization is used to describe the operation to equalize the cell voltages under the same conditions (e.g. temperature) during charge or discharge states.

[0034] The term state-of-charge is used to define the remaining charge of the battery relative to its rated capacity.

[0035] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

Exemplary Embodiments

[0036] Generally, the present invention provides a battery pack having a plurality of electrically coupled UBMs and a MCM for controlling the battery pack. Each UBM has rechargeable electric power cells and primitive control circuitry capable of communicating control signals with other UBMS as well as a MCM using standard electrical interfaces and communication protocols over a CAN bus. The MCM is an advanced control module, which provides pack safety control and operation control of the high voltage battery pack. Accordingly, the UBMs can be used as generic building blocks for battery packs of various sizes and configurations to accommodate a variety of applications.

[0037] The UBM is capable of simple system control and therefore a battery pack may need no MCM. Each UBM can communicate control signals with other UBMs concerning its temperature, cell voltages, module's voltage and module equalization command. When working without MCM in a battery pack, each UBM is capable of receiving current shunt inputs to monitor the state-of-charge and of sending electrical signals to drive application-related devices such as relays, breakers or contactors, warning light and charge/discharge power controls.

[0038] At the heart of the MCM is an advanced control unit that monitors the UBMs performance, calculates the pack state-of-charge and provides operating safety control. The MCM also includes contactors that are coupled to the control unit and can turn on/off the battery pack. The MCM further includes a current shunt, a voltage sensor, and a ground fault sensor coupled to the control unit and can provide readings of battery pack current, voltage and di-electric impedance.

[0039] The MCM has two separated electric connectors that can interface to UBMs and an external system control unit. It collects information from UBMs and report cell voltages, pack temperature distribution, pack state-of-charge, pack current, pack status and malfunction codes to an external control system (such as the control system in an electric vehicle) from which it receives commands to activate contactors accordingly.

[0040] Exemplary embodiments of the present invention are now described with reference to accompanying drawings, wherein like elements are designated by like reference numerals throughout the drawings.

Universal Battery Module

[0041] Due to its expandability and interchangeability, the battery pack comprising the UBMs in accordance with the present invention can be used in a variety of applications that utilize battery power. The battery pack is particularly suited for electric vehicles in which electric motive power is employed to drive the vehicle.

[0042] There is shown in FIG. 1(a) a battery pack **1a** having a plurality of UBMs **2a** to **2e** for use in an electric vehicle. The UBMs **2a** to **2e** serve as the basic building block for constructing the battery pack **1a**. The UBMs **2a** to **2e** are a rated 24V DC or 36V DC battery modules with built-in intelligent electric control and cooling circuit. In a typical power control system such as the power control system **3** for an electrical vehicle shown in FIG. 1(a), a plurality of UMBs **2a** to **2e** is connected in series to form the battery pack **1a** to provide sufficient power to drive the electric vehicle. The UBMs **2a** to **2e** are electrically coupled to a MCM **102**, which controls the operation of the entire battery pack **1a**.

[0043] The battery pack **1a** comprising the UBMs is electrically coupled to a charger **5** through a high voltage DC power bus **7** for re-storing energy in the UBMs **2a** to **2e**. The charger **5** serves to charge the battery pack **1a** during the charging stage and is a 220VAC to 120VDC power converter with its DC power controlled by charger control signals from MCM **102**. Not only the DC power bus **7** carries charging power from the charger **5** to the battery pack **1a**, it also transfers power discharged from the battery pack **1a** to other vehicle devices. Accordingly, during the discharging stage, power stored in the battery pack **1a** is discharged and transferred to an inverter **9** that is electrically coupled to the DC power bus **7** and a traction motor **11** for propelling the vehicle. The inverter **9** converts DC power from the battery pack **1a** to AC power to drive the traction motor **11**. The traction motor **11** is mechanically coupled to a drive shaft **13**, which transmits mechanical energy to the vehicles wheels **15** and causes the vehicle to advance. Similarly, a power steering pump **17** that is electrically coupled to the DC power bus **7** provides electrical power to the power steering motor **19** of the vehicle. A power converter **21** coupled to the DC power bus **7** converts power from the battery pack **1a** and charges the vehicle's battery **23**, which serves to supplement power to various peripheral devices such as the lights **25**, inverter **9**, and instrument cluster **35** of the electric vehicle.

[0044] Advantageously, the DC power bus **7** is a standardized power bus. As a result, not only the battery pack **1a** can be easily detached from the power control system **3** for testing or replacement, but also the battery pack **1a** is compatible for use in other systems with different voltage requirements.

[0045] At the heart of the control system **3** is a controller **27**, which is electrically coupled to a serial link CAN bus **29** for monitoring the operational status of various devices of the vehicle and to controls the flow of electric power on the DC power bus **7**. The controller **27** also controls various operational aspects of the vehicle by communicating control signals over the CAN bus **29**.

[0046] The instrument cluster **35** is electrically coupled to the controller **27** by way of the CAN bus **29** and displays information concerning the status of the vehicle and the battery pack **1a** to the vehicle's operator. Preferably, the instrument cluster **35** should indicate all necessary information concerning the safety and reliability of the batter pack **1a**. The operator can star-up or shut down the vehicle using the ignition key **37**, or control the vehicle by the accelerator **39** or the brakes **41** that are connected to the controller **27**. Signals from the ignition **37**, accelerator **39**, or brakes **41** are communicated to the controller **27**, which controls the vehicle in accordance with the instructions of the operator.

[0047] In a high power application such as the electric vehicle control system shown in FIG. 1(a), heat dissipation becomes an important concern. Accordingly, pump **43** provides coolant circulation in conduits **45**, **47** to cool and thermally equalize the UBMs **2a** to **2e**.

[0048] Referring now to FIG. 1(b), there is shown a block diagram showing the components of an electric vehicle including a battery pack having a plurality of UBMs in an exemplary low voltage electric vehicle application. The battery pack **1b** shown in FIG. 1(b) is suitable for low voltage applications and includes UBMs **2a** and **2b**. The battery pack **1b** is similar to the battery pack **1a** shown in FIG. 1(a), except that unlike the battery pack **1a**, the battery pack **1b** does not include a MCM **102** (shown in FIG. 1(a)). Instead, the UBMs **2a** and **2b** each include a built-in controller (not shown) that can be configured to control the battery pack **1b**. In the presently described embodiment, the UBM **2b** is responsible for controlling the battery pack **1b**. Not only the UBM **2b** monitor and control its own operational aspects, it also controls and interfaces with several external devices such as the instrument cluster **35** and the ignition key **37**.

[0049] The UBM **2b** receives signals from various sensors such as the shunt current sensor **31**, which communicates the value of the current on the DC power bus **7** to the UBM **2b**.

[0050] A contactor **33** connected to the DC power bus **7** is also electrically coupled to the UBM **2b** and receives control signals from the UBM **2b**. In the event that the operating conditions of the vehicle exceed the safe operating levels, the UBM **2b** opens the contactor **33** to discontinue the flow of power on the DC power bus **7**.

[0051] Reference is now made to FIG. 2, which shows an exemplary embodiment of a UBM in a battery pack (such as the battery pack **1a** in FIG. 1(a)) according to the present invention. The UBM **2** shown in FIG. 2 includes a shell **4** coupled to a base plate **8** in a preferably hermetically sealed relationship to prevent moisture from penetrating the shell **4**. The shell **4** contains therein a plurality of electrochemical battery cells **6** that are transversely positioned within a thermal frame **20** in a side-by-side fashion. The thermal frame **20** is in intimate contact with the cells **6** and is thermally coupled to base plate **8** to drive heat away from the cells **6**. Moreover, the thermal frame **20** retains the cells **6** in thermal relationship to provide thermal balancing between the cells **6**. Accordingly, if the temperature of a particular cell **6** abnormally rises during operation due to malfunction, the thermal frame **20** will distribute the excess heat throughout its frame thereby preventing a hotspot to occur. Advantageously, the thermal frame **20** is made of thermal conductive materials such as aluminum that equalize the temperature between cells **6**.

[0052] In one embodiment, the base plate **8** is further configured to include channels (not shown) that are fluidly connected to inlet **10** and outlet **12** to allow liquid coolant circulate in the base plate **8** for improved heat dissipation. In another embodiment, the UBM **2** also includes a liquid cooling circuit that cools each cell **6** in the UBM **2** by circulating a liquid coolant around the thermal frame **20**.

[0053] The cells **6** are electrically connected to one another in a series configuration by way of voltage conductors **50**. In the presently described embodiment, the cells **6** are Lithium-ion battery cells that are connected in series to provide the voltage in the range of 24V DC or 36V DC through the anode **16** and cathode **18** terminals of the UBM **2**. However, as it can be appreciated by those skilled in the art, the cells **6** can be connected in parallel, or a parallel series combination.

[0054] The UBM **2** is operational between two different states, namely a charge state, and a discharge state. During the charge state, the UBM **2** terminal voltage will increase when its state-of-charge increases by converting electric energy into chemical charges stored in the cells **6**. During the discharge state, the UBM **2** voltage goes down when its state-of-charge decreases and releases the stored energy.

[0055] For each cell **6**, a bypass resister **48** is connected across the terminals of the cell **6** to bypass the charge or discharge current. When a cell **6** voltage is higher than others during the charge state, the bypass resistor **48** reduces the charge current. When a cell **6** voltage is lower than others during the discharge state, the bypass resister **48** acts to reduce the discharge current.

[0056] Each UBM **2** in a battery pack (such as the battery pack **1a** shown in FIG. 1(a)) comprises identical control logic and functional capabilities for self-initiated control of the physical parameters of the local UBM **2**. Accordingly, the UBM **2** includes a Battery Control Unit (BCU) **14** that monitors the cell **6** voltages and module temperature, controls voltage equalizations between cells **6** and communicates various information regarding status of the UBM **2** during charge and discharge states to other UBMs **2** and the master control module MCM which is described in further detail in connection with FIG. 4 hereinafter.

[0057] In the presently described embodiment of the invention, the BCU **14** is implemented using a controller as defined herein. The BCU's **14** memory includes predefined values for the temperature and voltage thresholds of the UBM **2**. The predefined values are stored in the BCU **14** memory in a look-up table. The BCU **14** is electrically coupled to a connector **24** to communicate signals corresponding to the operating status of the UBM **2** to a MCM, or other UBMs **2** in a battery pack.

[0058] The connector **24** protrudes from the shell **4** and provides terminals **26** to **46** for connection with a serial communication CAN bus, for instance the CAN bus **29** in FIG. 1(a). Alternatively, the connector **24** can be configured such that it would directly connect with a mating connector from a subsequent UBM **2** in a battery pack. Through terminals **26** to **46**, the BCU **14** transmits electrical control signals corresponding to various aspects of the UBM **2** over the serial communication CAN bus such as the CAN bus **29** in FIG. 1(a) that is electrically coupled to terminals **26** to **46** in order to transmit or receive control signals from peripheral devices in a power control system. Preferably, the control signals are adapted to drive relays, contactors, or similar actuating devices.

[0059] In a battery pack comprising a plurality of UBMs **2** such as the UBMs **2a** to **2e** in the battery pack **1a** shown in FIG. 1(a), each BCU **14** needs a communication channel for passing its control signals to other BCUs **14** in the battery pack. This can be achieved by coupling terminals **26** and **28** of each BCU **14** to a serial communication bus such as the CAN bus **51** shown in FIG. 1(a), which serves as the main communications channel for the various BCUs **14** in the battery pack. The BCUs **14** can optionally communicate with each other on the serial communication CAN bus using a master or a proprietary CAN communication protocol.

[0060] For small applications that need low voltage battery system, these control signals can be used to provide basic system control without using an external controller for controlling the entire battery pack. The control signals will not be used (not connected) when building a large battery pack with an internal MCM for controlling various operational aspects of the battery pack.

[0061] The signals available at terminals **26** to **46** are summarized in the Table 1 below:

Table 1: UBM terminal description

Terminal	Function	Control Signals
26	CAN+	CAN Bus, UBM voltage, current
28	CAN-	State-of-Charge, di-electric impedance, fault code, etc.
30	Ignition	Ignition On/Off
32	Warning Light	Flashing when charging Solid when over or under voltage or over temperature
34	Power Control	Charger control
36	Sequence UP	Input signal for automatic numbering
38	Sequence DOWN	Output signal for automatic numbering
40	GND	Chassis ground
42	Contactor	Contactor control, Safety control
44	Diff IN+	Shunt current sensor Differential input+
46	Diff IN-	Shunt current sensor Differential input-

[0062] As indicated in Table 1, The connector **24** further communicates other control signals generated from the BCU **14**, such as a contactor signal at terminal **42**, a warning light signal at terminal **32**, and power control signal at terminal **34** to provide simple system operation control and differential shunt voltage inputs Diff IN+ **44**, and Diff IN- **46** to measure the current of the battery pack (such as the battery pack **1b** shown in FIG. 1(b)). For example, in the low voltage application of FIG. 1(b), the current shunt **35** communicates the value of the current on DC power bus **7**. Terminal **36** communicates a "sequence UP" signal from the BCU **14** that is the input to the present UBM **2** enable/disable the sequence number arbitration of UBM **2** within the battery pack. Terminal **38** indicates a "sequence Down" signal from the BCU **14** that is the output to enable/disable the next adjacent UBM **2** to arbitrate the sequence number of the UBM **2** in the plurality of UBMs **2** in a battery pack for an external controller to recognize it. In the event there are only two UBM **2** in the battery pack, the single UBM **2** with no "sequence Up" input connection is considered as the first UBM **2** which will be responsible for simple system control. This is the case with UBM **2b** described in FIG. 1(b).

[0063] High power batteries, particularly those used in automotive applications such as the one shown in FIGs. 1(a) and 1(b), generate tremendous amounts of heat during operation. Not only the heat reduces the life of the cells **6**, but also it is hazardous to safe operation of the system incorporating the power system **3**. To control the thermal characteristics of the UBM **2**, a heat sensor **22** (such as a thermostat) is provided to monitor the heat generated by the cells **6**. The heat sensor **22** is in thermal relationship with the thermal frame **20** and electrically connected to the BCU **14**. The BCU **14** constantly monitors the temperature of the UBM **2** and compares the temperature with the predefined acceptable threshold stored in the BCU **14**. There are two levels of threshold: (i) warning threshold; and (ii) off threshold. If the UBM **2** temperature exceeds the predefined warning threshold, the BCU **14** will first sends a warning flag on signal at terminals **26** and **28** so as to communicate the warning flag via the CAN bus **29** to the controller **27** (as shown in FIG. 1(a)). The BCU **14** will only shut down the UBM **2** if the temperature continues to rise pass the threshold.

[0064] The BCU **14** sends the warning light signal at terminal **32** with its duty cycle in reverse of the battery pack state-of-charge. For instance, when state-of-charge is larger than 60%, the warning light **32** is set to duty cycle 2%; when state-of-charge is 5%, the warning light **32** duty cycle is 99%. Similarly, when the BCU **14** detects that the operating temperature of the UBM **2** exceeds a safety limit, the state-of-charge is less than 3% or that the UBM **2** is over voltage or under voltage, it will keep the warning light signal at a duty cycle of 99%. The warning light signal at terminal **32** is optionally transmitted to a warning light **52** that is connected to terminal **32**, which would indicate a solid light when the UBM **2** is over or under voltage, over discharged, or when the temperature of the UBM **2** exceeds the predetermined thresholds.

[0065] Under normal operating conditions, the module power control signal available at terminal **34** is set at 98% duty cycle. If any cell **6** voltage is closer to a predetermined constant voltage set point, the power control signal duty cycle will start reducing down to 2%. This signal can be used to control a charger (such as charger **5** shown in FIG. 1(a)) coupled to the UBM **2** whose charging power is proportional to its control input signal duty cycle. When the control signal duty cycle is reducing, the charger output power is reducing and therefore no cell **6** voltage will exceed the constant voltage set point. A proportional integral derivative (PID) algorithm is implemented in BCU **14** in software or firmware, which constantly monitors the voltage and maintains the cell voltage below a set point.

[0066] As shown in FIG. 1(b), a current shunt **35** can be electrically connected in series to the battery pack's output power terminal **18** to provide differential feedback to BCU **14**, thereby allowing the BCU **14** to monitor the current characteristics of the battery pack in either the charge or discharge states. This current shunt **35** is electrically coupled to BCU **14** through terminals Diff IN+ **44**, and Diff IN- **46** and communicates the current characteristics to the BCU **14** for monitoring the battery state-of-charge.

[0067] Reference is now made to FIG. 3, which shows a flow diagram indicating the steps involved in equalization and charging of cells **6** by BCU **14**. These steps can be implemented in BCU **14** by firmware or software in BCU **14**. For the purposes of FIG. 3, it is assumed that there are N cells **6** in a battery pack. When the power on signal at terminal **30** is detected (Step **S10**), the BCU **14** enters the operation mode wherein it continuously monitors the cell equalization status. When during charging the cell **6** voltages become diversified, the BCU **14** will enter cell electric equalization mode to equalize the cells **6** (e.g. turn on the bypass circuit of those cells **6** whose voltage is above or below the average voltage of the cells **6** within the UBM **2** with a predetermined error). At the same time, the BCU **14** continuously reports the maximum and minimum cell **6** voltages as well as UBM **2** temperature via the serial communication CAN bus

29 (shown in FIG. 1(a)). Accordingly, the BCU **14** first calculates the average cell **6** voltages to determine the average cell voltage V_{ave} (Step **S12**). The BCU **14** then verifies whether the cells 6 have been in the charging state for more than 2 seconds (Step **S14**). If the cells **6** have been charged for over 2 seconds, the BCU **14** compares the voltage V_i of each cell **6** with the average voltage V_{ave} plus the voltage threshold (Step **S16**).

[0068] If the cell **6** voltage V_i is larger than the combination of average voltage V_{ave} plus the voltage threshold, the BCU **14** switches on a bypass circuit BC_i for that particular cell **6**, so as to bypass some current from charging the cell **6**. (Step **S18**). However, if the cell **6** voltage V_i is within the voltage threshold, the BCU **14** shuts off the bypass circuit BC_i **48** for that cell **6** (Step **S20**). The BCU **14** subsequently determines the maximum cell voltage V_{max-i} for the cell **6** (Step **S22**). At this juncture, the BCU **14** determines Dv according to the following equation: $Dv = V_{sp}(T) - V_{max-i}$, whereby Dv corresponds to the difference between the charge cell **6** voltage set point $V_{sp}(T)$ for the current operating temperature T of the UBM **2**, and the V_{max-i} for the cell **6** (Step **S24**). On the basis of the Dv, the BCU **14** sets the charger's duty cycle from the PID algorithm. The duty cycle is set not to exceed 98% or fall below 2% (Step **S26**).

[0069] If the cells **6** have not been charged for over 2 seconds, the BCU **14** then checks to see whether the cells **6** have been discharging for more than 1 second (Step **S28**). In the event the cells **6** have not been discharging for over 1 second, then all the bypass circuits within the UBM **2** are turned off (Step **S30**) and the charger's (such as charger **5** in FIG. 1(a)) duty cycle set to 2% (Step **S32**).

[0070] During the discharge state, a power control signal is used to indicate the maximum discharge power allowed. Therefore, if the cells **6** have been discharging for over 1 second, discharge state is confirmed and the power control signal duty cycle is set as a percentage of the current discharge power over the maximum allowed discharge power (Step **S38**).

[0071] If the cells **6** have been discharging for over 1 second, then the BCU **14** compares the voltage V_i of each cell **6** with the average voltage V_{ave} plus the voltage threshold (Step **S34**). If the cell **6** voltage V_i is smaller than the combination of average voltage V_{ave} plus the voltage threshold, the BCU **14** activates the bypass circuit BC_i for the cell **6** in order to bypass some current from discharging the cell **6** (Step **S36**). However, if the cell **6** voltage V_i is within the voltage threshold, the BCU **14** shuts off the bypass circuit BC_i for that cell **6** (Step **S40**).

Master Control Module

[0072] Reference is now made to FIG. 4, which illustrates a Master Control Module (MCM) **102** for controlling a battery pack (such the battery pack **1a** shown in FIG. 1(a)). The MCM **102** is an interface and control module that monitors operating parameters of the entire battery pack and manages the UBM **2** resources to achieve the safe operation of the battery pack.

[0073] As illustrated in FIG. 4, the MCM **102** includes internal positive **120** and negative **122** power terminals, external power positive **108** and negative **106** terminals, and a controller coupled to a first connector **112** for internal serial communication with at least a UBM **2** in a battery pack (not shown in FIG. 4). The MCM **102** communicates control signals with the UBMs **2** by way of a serial communication link, such as CAN bus, that is coupled to the terminals of the connector **112**.

[0074] The MCM **102** further includes a second connector **110** for external serial communication with various peripheral devices such as the battery charger in a system. Accordingly, the MCM **102** separates the external serial communication with the internal serial communication with two serial buses CAN1 bus **113** and CAN2 bus **111** coupled to the first connector **112** and second connectors respectively **110**, respectively. The MCM **102** and its interfaces, include the following signals as described in Table 2 below:

Table 2: MCM terminal description

Terminal	**Function**	**Control Signals**
128	CAN+	CAN Bus
130	CAN-	CAN Bus
132	Ignition	Ignition On / Off
134	Warning Light	Flashing when charging Solid when over or under voltage or over temperature
136	Power Control	Charger control
138	Safety Interlock+	Energized during operation
140	Safety Interlock-	Energized during operation
142	GND	Chassis ground

[0075] The MCM **102** also includes a main contactor **124**, a precharge contactor **126**, a current shunt **116**, a fuse **118** and a controller **114** that includes a di-electrical impedance detection circuitry. It supports battery packs of voltages above 72V with internal CAN1 bus **113** isolated from the CAN2 bus **111** which interfaces directly to the system control serial communication bus. The MCM **102** optionally includes a fuse that will disconnect the power to the battery pack when the battery pack is short-circuited. It can switch on/off the high voltage bus by built-in contactors **124, 126**, which are controlled according to CAN, command or power on signal.

[0076] The safety interlock terminals **138, 140** are to enable the closing of the built-in contactors **124, 126**. Only when energized, the contactors **124, 126** can be closed to output power or accept charges. This protection allows the high voltage power from the battery pack to be cut off in emergency by a physical switch.

[0077] The UBM **2** is generally maintained in a voltage range during the charge stage so as to prevent over voltage during charging and maximizing the charging of the battery pack. The MCM **102** monitors both the cell **6** (shown in FIG. 1(a)) voltages and the charging current supplied to the battery pack comprising a number of UBMs **2** (such as UBMs **2a** to **2e** in battery pack **1a** shown in FIG. 1(a)) and controls the charging power via power control signal **136** during a charge cycle so as to prevent overcharging of the battery pack.

[0078] The MCM **102** can also be configured and arranged to send an electrical signal to drive the warning light and charger. Advantageously, the MCM **102** is configured to further monitor the battery pack charge/discharge current and high voltage bus di-electric impedance level (Ohm) with a SAE recommended circuit (not shown). In another embodiment, a voltage sensor is provided to determine the voltage from the battery pack. Accordingly, the MCM **102** can also monitor the battery pack instantaneous and average voltage based on sensed voltage communicated to the MCM **102** by the voltage sensor.

[0079] Reference is now made to FIG. 5, which illustrates the steps in the start-up operation of the MCM **102** shown in FIG. 4. Initially, the MCM **102** monitors the CAN2 bus **111** to determine whether a CAN signal has been received on CAN2 **111** (Step **S52**). If a CAN signal has been initiated from the power control system (such as the power control system **3** shown in FIG. 1(a)), the MCM **102** retrieves from its memory the: (i) Saved time when the pack is switched off; (ii) the pack state-of-charge from last switched off; (iii) accumulated Energy In and Out in the battery pack's life; (iv) accumulated Operating Time in the battery pack's life; and (v) Accumulated Fault Codes in the battery pack's life (Step **S54**). The MCM **102** then calculates the resting time of the battery pack (Step **S56**) since it was last switched off. The MCM **102** resolves whether the rest time exceeds a predetermined time frame, for instance 3 hours (Step **S58**). If the rest time is longer than 3 hours, then the MCM **102** obtains the battery pack open circuit voltage V_{oc} (Step **S60**), on the basis of which, it calculates a new SOC for the battery pack (Step **S64**). The MCM **102** proceeds to obtain the di-electric impedance R_{di} of the battery pack (Step **S66**). If the rest time is not longer than 3 hours, the MCM **102** uses the saved SOC operation value (Step **S68**) as the new SOC value. The new SOC is used for columbic integration calculation (Step **S64**) as the initial value and directly proceeds to obtain from the di-electric detection circuit **114** the di-electric impedance R_{di} of the battery pack (Step **S66**).

[0080] The MCM **102** proceeds to measure the di-electric impedance R_{di} of the battery pack (Step **S66**) and communicates the di-electric impedance R_{di} on the CAN bus (Step **S70**) and compares the di-electric impedance R_{di} with the threshold value (Step S72). If the di-electric impedance R_{di} is less than the threshold value, the MCM **102** sets a warning flag and communicates the flag via the CAN bus. The MCM **102** then checks whether there is a power up command on the CAN2 bus **111** (Step **S76**). If the di-electric impedance R_{di} is larger than the threshold value, the MCM **102** will wait the power up/down command via CAN2 bus **111** from the system controller (Step **S76, S78**). If there is a power up command on the CAN2 bus **111,** then the MCM **102** switches on the precharge contactor (Step **S80**), otherwise it will wait for a the power up command from CAN2 bus **111** (Step **S76**).

[0081] To control the precharging, the MCM **102** monitors the battery pack output voltage V_c and the precharging time (Step **S82**). If the output voltage V_c is larger than 90% of a threshold voltage level V_{oc} (Step **S84**), then the MCM **102** activates the main contactor (Step **S86**), sets startup flag and updates via the CAN bus 111 (Step **S88**), and saves the start-up time from the built-in real-time clock (Step **S90**). If the output voltage V_c is less than 90% of the V_{oc} (Step **S84**), the MCM **102** verifies whether the precharging timer is timeout (Step **S92**). If not, then the MCM **102** MCM **102** monitors the battery pack output voltage V_c and monitors the waiting time (Step **S82**). In the event that the timer is timeout, the MCM **102** sets fail precharge flag and updates via the CAN2 bus **111** (Step **S94**) and switches off the precharge contactor (Step **S96**).

[0082] Reference is now made to FIG. 6, which in conjunction with FIG. 2, illustrates the steps in the start-up operation of a UBM **2**. Initially, the UBM **2** monitors a CAN bus coupled to the BCU **14** terminals **26** and **28**. If there is a MCM **102** present in the battery pack, its CAN1 bus **113** (shown in FIG. 4) is coupled to the BCU **14** terminals **26** and **28.** The BCU **14** monitors the CAN1 bus **113** and waits for a CAN command placed on the CAN1 bus **113** by the MCM **102** or other UBMs **2** in the battery pack (Step **S102**). If a CAN command has been received, either from the MCM **102** or other UBMs **2,** the BCU **14** will further check whether it is the first UBM **2** (i.e. no MCM **102** in the battery pack) in the pack (Step **S104**).

[0083] If the UBM **2** it is not the first UBM (i.e. there is a MCM **2** present in the battery pack), the BCU **14** retrieves from its memory the: (i) accumulated Operating Time in the battery pack's life; and (ii) Accumulated Fault Codes in the battery pack's life (Step **S126**) and finalizes the startup process (Step **S128**).

[0084] If the UBM **2** is the first UBM, its BCU **14** has to initialize to provide battery pack control functions. The BCU **14** therefore retrieves from its memory (i) Saved time when the pack is switched off; (ii) the pack state-of-charge from last switched off; (iii) accumulated Energy In and Out in the battery pack's life (Step **S106**).

[0085] To determine the initial SOC, the BCU **14** first calculates the battery pack resting time (Step **S108**). The BCU **14** then checks whether the battery pack has been inactive for over 3 hours (Step **S110**). If the battery pack rested for not longer than 3 hours, the BCU **14** uses the saved SOC value as the initial integration value to calculate battery pack SOC during the following operation (Step **S118**). If the battery pack rested for longer than 3 hours, the BCU **14** will read the pack open circuit voltage (Step **S112**) and use it to calculate the new SOC (Step **S114**) as the initial integration value to calculate pack SOC during the following operation (Step **S116**).

[0086] After finishing initial SOC calculation, BCU **14** will initialize the battery pack by saving the startup time to its memory for later use to calculate operation time (Step **S120**) and reset warning light signal duty cycle to 3% (warning light off) and reset power control signal duty cycle to 2% (charger power off) (Step **S122**). When the above initialization completed, BCU **14** will switch on the contactor (Step **S124**) to supply power (e.g. for vehicle driving) or receive charging. The BCU **14** retrieves from its memory the: (i) accumulated Operating Time in the pack's life; and (ii) Accumulated Fault Codes in the pack's life (Step **S126**) to complete the startup processing (Step **S128**).

[0087] There are generally five UBM and four MCM operational modes that are deemed required in a typical application. During a typical operation cycle, the battery pack operating mode may be switched between the available modes in response to system control requests. These modes can be implemented in software or firmware as known by those skilled in the art.

[0088] Referring now to FIG. 7, a state diagram illustrating various modes of operation of a UBM 2 shown in FIG. 2. As illustrated, the UBM **2** may operate in the following modes: (i) initialization mode **301**; (ii) operation mode **302**; (iii) service mode **304**; (iv) sleep mode **306**; and (v) control mode **308** in operation.

[0089] In the initialization mode **301**, the BCU **14** reboots. In this mode, the BCU **14** will reload the parameters include CAN communication baud rate and repetition rate and conduct module sequence number arbitrations. There are three cases that UBM **2** will enter initialization mode: (i) from first time power up **300**; (ii) external service reset command from service mode **304**; and (iii) UBM **2** watchdog reset from normal operations, **302** or **308**.

[0090] During operation mode **302**, the BCU **14** will continuously monitor the cell **6** voltages and UBM **2** temperature. Base on the cell **6** voltage distribution, the BCU **14** may turn on/off cell equalization bypass circuits to equalize the cell **6** voltages. When over voltage of any cell **6** or over temperature of the UBM **2** are detected, the BCU **14** sends alarm signals through CAN1 bus **113**.

[0091] The BCU **14** also sends data (such as information concerning the cells **6** voltage or temperature) periodically to the MCM **102**. When synchronized voltage measuring command via CAN1 bus **113** is received from MCM **102** or the first UBM **2**, the BCU **14** will sample all the cell **6** voltages and report via CAN1 bus **113** immediately. When a global equalization command is received by the BCU **14** from the CAN1 bus **113**, all the cell **6** equalization circuits will be turned on until removal of the command.

[0092] In low voltage applications such as those shown in FIG. 1(b) where the first UBM **2b** controls the battery pack functions, the BCU **14** for the first UBM **2** will open the contactor **33** if the alarm flags from CAN1 bus **113** from any UBM **2** exists continuously for more than three updates of the CAN messages or more than three UBMs **2** report the alarms at the same time, and turns on the warning light when over voltage of any cell **6** or over temperature of the UBM **2** are detected.

[0093] In the service mode **304**, the BCU **14** can upload new software (or firmware) or update the parameters to its memory. The new uploaded software or parameters won't take effect until the next time the UBM **2** enters into the initialization mode **301**. Accordingly, if the reset command is present on the CAN1 bus **113**, the BCU **14** reloads the new software or parameters and re-initializes itself to its new configurations, reloads the new version of software. During the service mode **304**, the BCU **14** is configured to transmit via the CAN1 bus **133** operating status information (such as cell **6** voltages, UBM **2** temperature, current operating parameters, error codes, etc.) for diagnostics purposes.

[0094] During the sleep mode **306**, at ignition off (i.e. terminal 30 of the BCU **14**), UBM **2** enters sleep mode for energy conservation and to reduce the power consumption. While in the sleep mode **306**, all BCUs **14** (include CPU, CAN transceiver and power regulators) will enter sleep mode and can be woken up at ignition power on.

[0095] During the initialization mode **301**, if the UBM **2** determines that it is the first module (with no enable input) in a battery pack and there is no MCM **102**, it enters the control mode **308**. In this mode, the BCU **14** not only controls the UBM **2** as in operation mode **302** but also monitors the battery pack current via shunt differential inputs and controls the warning light, contactor and power control to provide basic power on/off and charging control. In the control mode **308**, the BCU **14** also transmits control signals such as synchronized voltage measurement or global equalization over the CAN bus to other UBMs **2** for battery pack equalization. In a preferred embodiment, these control signals can be communicated to an instrumentation cluster (such as the instrument cluster **35** shown in FIG. 1(a)) for display of the battery pack state-of-charge and fault status.

[0096] Reference is now made to FIG. 8, which shows a state diagram illustrating various modes of operation of the MCM **102** of FIG. 4. As indicated in FIG. 8, the MCM **102** modes of operation are as follows: (i) initialization mode **401**; (ii) operation mode **402**; (iii) sleep mode; and (iv) service mode.

[0097] For first time power up at Start-up mode **400**, the MCM **102** enters the initialization mode **401**, whereby it reloads saved parameters (such as CAN bus baud rate, CAN communication update rate, SOC, accumulated charge/discharge columbic, accumulated working hours, etc.) and fault information from last power on cycle.

[0098] In the operation mode **402**, the MCM **102** controls basic battery pack operations, namely, module equalization, system precharge and main power on/off. At the same time the MCM **102**

monitors the battery pack current, voltage and high voltage bus dielectric impedance, and calculates battery pack SOC and charge/discharge capacity. It reports these values regularly with operating modes as well as fault status via CAN2 bus **111** to the power control system (such as the power control system **3** shown in FIG. 1(a)).

[0099] In the service mode **404**, MCM **102** can upload new software (or firmware) or update the parameters to its memory. The new uploaded software or parameters won't take effect until the next time the MCM **102** enters into the initialization mode **401**. If the reset command is present on the CAN2 bus **111**, the MCM **102** reloads the new software or parameters and re-initializes itself to its new configurations. Moreover, during the service mode **404**, the **MCM 102** is configured to transmit via the CAN2 bus **111** operating status information concerning the UBM **2** (UBM **2** voltage and current, UBM **2** temperature, error codes, etc.) for diagnostics purposes.

[00100] In the sleep mode **406,** the MCM **102** enters sleep mode to save power consumption. At the same time, it will keep the real time clock working to track the rest and operation time of the battery pack.

[00101] Referring now to FIG. 9, a battery pack **60** is shown having two UBMs **2a** and **2b** that are electrically coupled in series. Such a battery pack **60** is suitable for low voltage applications, such as All-Terrain-Vehicles (ATVs), golf carts, or scooters for the physically challenged. As shown in FIG. 9, the battery pack **60** includes UBMs **2a, 2b** having BCU **14a, 14b**, respectively. BCU **14a** and **14b** communicate with each other through connectors **24a, 24b** through a serial communication bus **25**. The BCU **14b** uses its standard control outputs to provide basic control of the UBMs **2a, 2b.** A connector **62** is electrically connected with connector **24b** to communicate control signals from the UBM **2b** to an external bus (not shown). For low voltage low cost applications such as ATVs, an external bus is typically not present. In these applications, there may be no external serial bus communication during operation except for services such as diagnostics, software update, calibration update, etc. by connecting an external controller such as a Personal Computer equipped with a CAN card to the CAN1 bus **113**. In the presently described embodiment, the CAN communication terminals 26 and **28** are used for service operation control only, and include software or parameter upload/download and system reset. The power on signals (Ignition **30** and GND **40**) are the operation control signals with Diff IN+ **44**, and Diff IN- **46** indicating the pack **60** current.

[00102] Although in most low voltage applications the operational temperature of the battery pack **60** does not reach critical levels, a heat sink (not shown) can optionally be thermally coupled to the battery pack shell **61** which thermally contacts tightly with battery module base plates to improve heat dissipation.

[00103] FIG. 10 shows a perspective view of a battery pack **70** having four UBMs **2a, 2b, 2c**, and **2d** that are electrically coupled in series, having BCU **14a, 14b, 14c**, and **14d**, respectively. The battery pack **70** is a high voltage pack that requires a MCM **102** to provide high voltage protections and battery pack power on /off control. It is suitable for high power applications, such as pure electric vehicles, hybrid electric vehicles, wind or solar energy storages. All the BUCs **14a, 14b, 14c**, and **14d** communicate with each other using the CAN2 bus **83, 81**.

[00104] The MCM **102** has its input power terminals **120** and **122** connected to the power terminals **18d** and **16d** of UBM **14d** respectively. The MCM **102** output power terminals **108**and **106** are the battery pack's **70** power interface. The MCM **102** communicates with the external devices such as the power control system **3** in FIG. 1(a) via connector **110** which has the same signals as those described in Table 2.

[00105] Within the pack **70**, the MCM **102** interfaces with UBM **2d** by internal electric connector **112** with signals include: (i) Sequence enable **85**; (ii) CAN+ **83**; (iii) CAN- **81**; (iv)Power On/Off **91**; and (v) Signal ground **89**. With MCM **102** to manage the pack **70** and to provide battery pack control, UBMs' **2a** to **2d** system control signals such as those described in Table 1 namely the warning light **32**, power control **34**, contactor control **42**, Diff IN+ **44**, and Diff IN- **46** are not required and therefore will not be connected and used.

[00106] For high power applications, the battery pack **70** requires liquid cooling with coolant in **45** and coolant out **47** for the purpose of both thermal cooling and thermal equalization between the UBMs **2a** to **2d**.

[00107] In the above examples, each battery pack comprises a single linear array of UBMs in series. However, alternative arrangements of UBMs are also possible. As shown in the exemplary embodiment of FIG. 11, the battery pack **80** includes an array of UBMs **2a** to **2h,** wherein two rows of four UBMs **2a** to **2d**, and **2e** to **2h** are retained side-by-side. The UBMs **2a** to **2h** of each row are aligned proximate to each other with their respective inlets **10a** to **10h** and outlets **12a** to **12h** are in alignment to permits improved flow of coolant within the cooling system. The UBMs **2a** to **2d** are connected to one another in parallel. Similarly, the UBMs **2e** to **2h** are connected to one another in parallel. The UBMs **2a** to **2d** in the first row are connected to the UBMs **2e** to **2h** in the second row in series. The UBM **2d** is connected to a MCM **102**, which is responsible for controlling the entire battery pack **80**.

[00108] It is obvious that the foregoing embodiments of the invention are exemplary and can be varied in many ways. Such present or future variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

MBM File No. 1448-103

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A universal battery module comprising:

a plurality of series connected battery cells;

sensor means coupled to the cells, the sensor means configured to transmit physical parameters of the cells;

a battery control unit in communication with the sensor means to control the cells based on physical parameters from the sensor means;

wherein the battery control unit, the sensor means and the cells are packaged together as a single integral module.

2. A universal battery module as set forth in claim 1, further comprising a shell for retaining the battery cells therein.

3. A universal battery module as set forth in claim 1, further comprising a thermal frame in thermal communication with the cells to provide cell thermal equalization.

4. A universal battery module as set forth in claim 2, further comprising a base plate coupled to the shell in a hermetically sealing relationship and in thermal communication with the thermal frame to enhance heat dissipation from the thermal frame.

5. A universal battery module as set forth in claim 4, wherein the base plate has an inlet, an outlet and a plurality of passes fluidly connected to the inlet and outlet for transmitting cooling liquid between the inlet and the outlet.

6. A universal battery module as set forth in claim 4, wherein the base plate is hermetically coupled to the shell in a sealing relationship.

7. A universal battery module as set forth in claim 1, further comprising cell electric equalization means.

8. A universal battery module as set forth in claim 1, further comprising an electrical connector coupled to the battery control unit, the electrical connector being configured to provide electric connections for serial communication, power on/off signal, control output signals and input signals.

9. A universal battery module as set forth in claim 8, wherein the serial communication bus is a CAN bus.

10. A universal battery module as set forth in claim 1, wherein the battery control unit is configured to generate control output signals relating to charge/discharge power control and warning light control.

11. A universal battery module as set forth in claim 1, wherein the battery control unit is configured to monitor the module current from the differential input signals.

12. A universal battery module as set forth in claim 1, wherein the battery control unit is configured to monitor the cell voltages, module current and module thermal frame temperature.

13. A universal battery module as set forth in claim 1, wherein the battery control unit configured to control the cell electrical equalization.

14. A universal battery module as set forth in claim 1, wherein the battery control unit isn configured to control the arbitration of the cell sequence numbers.

15. A battery pack comprising:

at least two universal battery modules in a string of connected universal battery modules, each universal battery module including a plurality of series connected battery cells, sensor means coupled to the cells and configured to monitor and transmit physical parameters of the cells, a battery control unit in communication with the sensor means to control the cells based on physical parameters from the sensor means;

a master control module coupled to the string of universal battery modules, the master control module configured to control the battery pack power on/off and including internal electrical connector means to interface with each universal battery modules and control means to control electric equalization of the string of universal battery modules;

wherein the string of universal battery modules and the master control module are packaged together as a single integral battery pack.

16. The battery pack as set forth in claim 15, wherein the universal battery modules are electrically connected in series.

17. The battery pack as set forth in claim 15, wherein the universal battery modules are electrically connected in parallel.

18. The battery pack as set forth in claim 15, wherein the master control module further comprises an external electrical connector means to interface with an external system controller via a serial communication bus to transmit charge/discharge power control, warning light control and safety interlock signals.

19. The battery pack as set forth in claim 15, wherein the master control module further includes ground fault sensor means that monitors di-electric impedance of the battery pack.

20. The battery pack as set forth in claim 15, wherein the master control module further includes a current shunt that monitors the battery pack current.

21. The battery pack as set forth in claim 15, wherein the master control module further includes a fuse to protect the battery pack from short circuit.

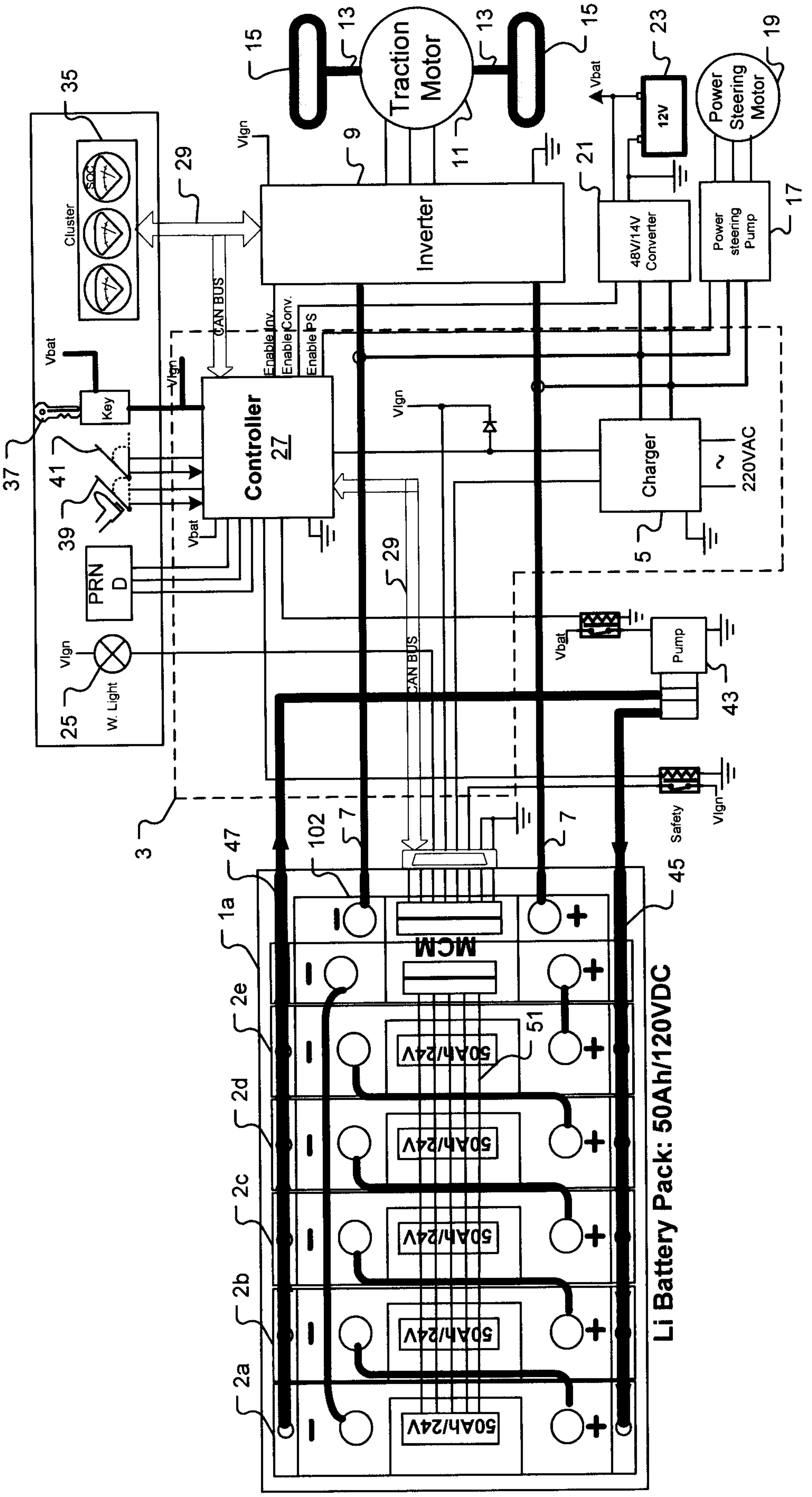
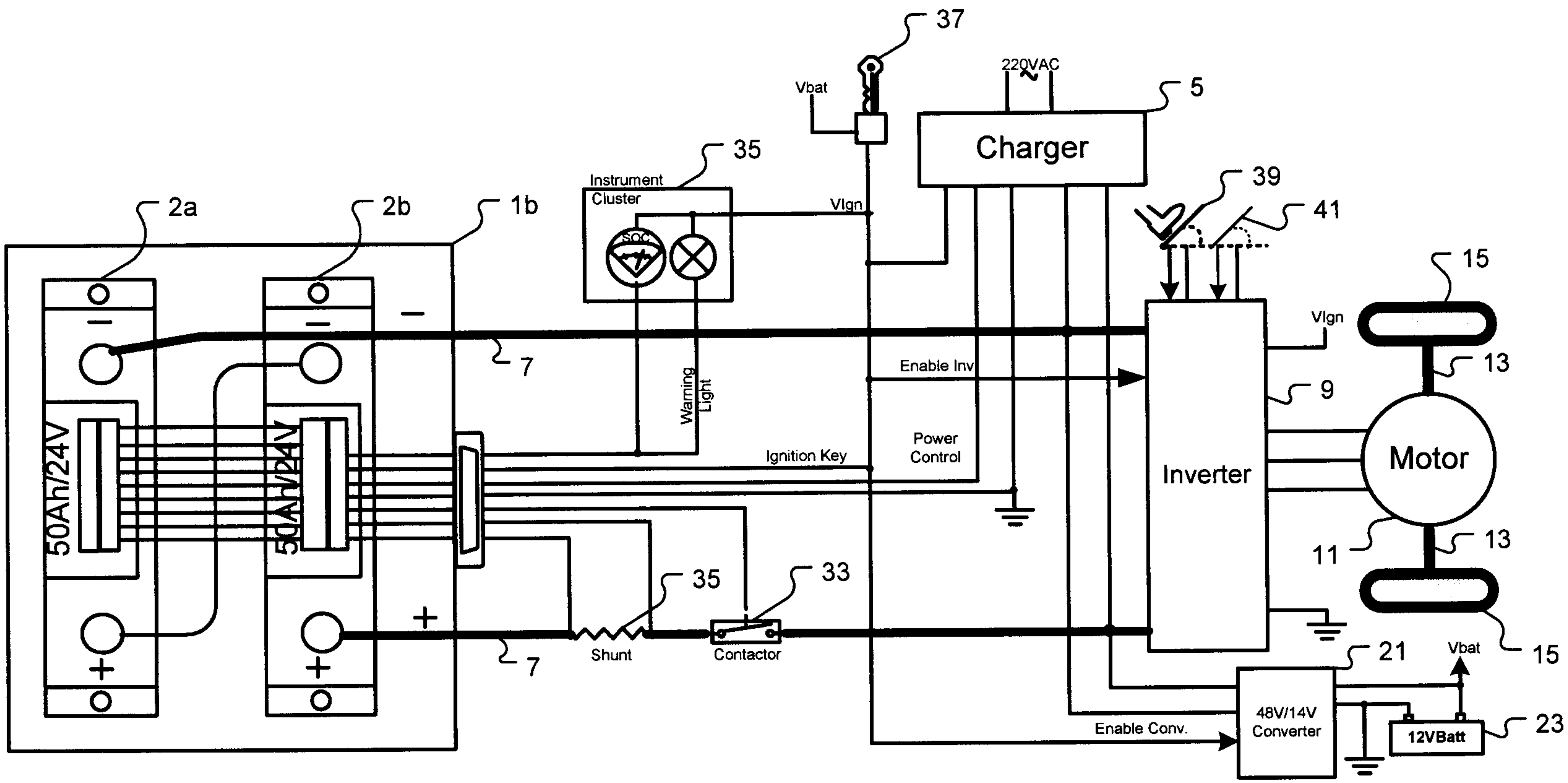

Traction Motor
Inverter
48V/14V Converter
12V
Power Steering Motor
Power steering Pump
Cluster
SOC
CAN BUS
Enable Inv.
Enable Conv.
Enable PS
Controller 27
Key
Vbat
VIgn
PRN D
W. Light
Charger
220VAC
Pump
Safety
MCM
50Ah/24V
Li Battery Pack: 50Ah/120VDC
1a
2a
2b
2c
2d
2e
3
5
7
9
11
13
15
17
19
21
23
25
29
35
37
39
41
43
45
47
51
102

FIG. 1(a)



Li Battery Pack: 50Ah/48VDC

FIG. 1(b)

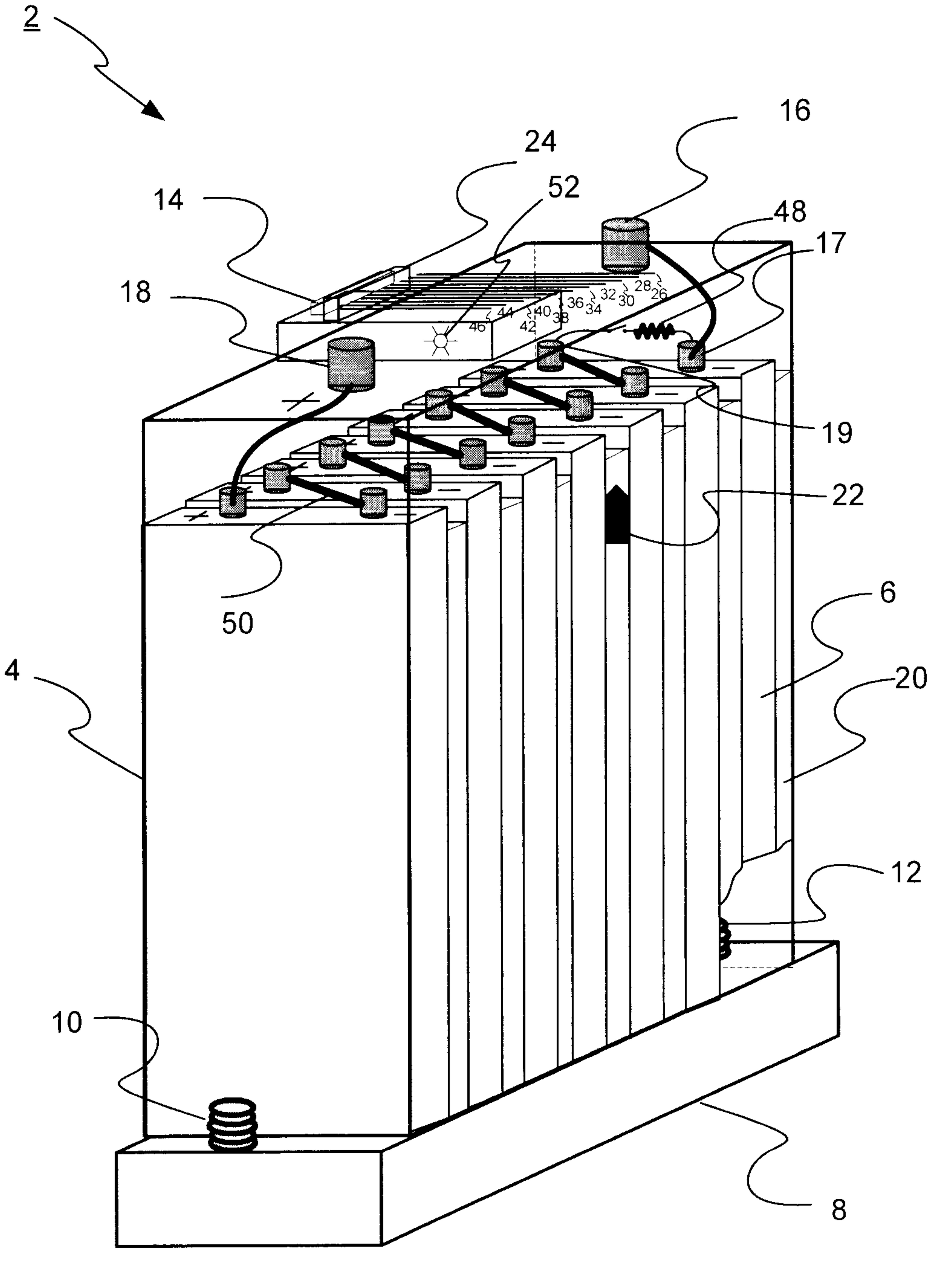

2
24
52
16
14
48
17
18
28
26
32
30
36
34
44
40
38
46
42
19
22
50
6
4
20
12
10
8

FIG. 2

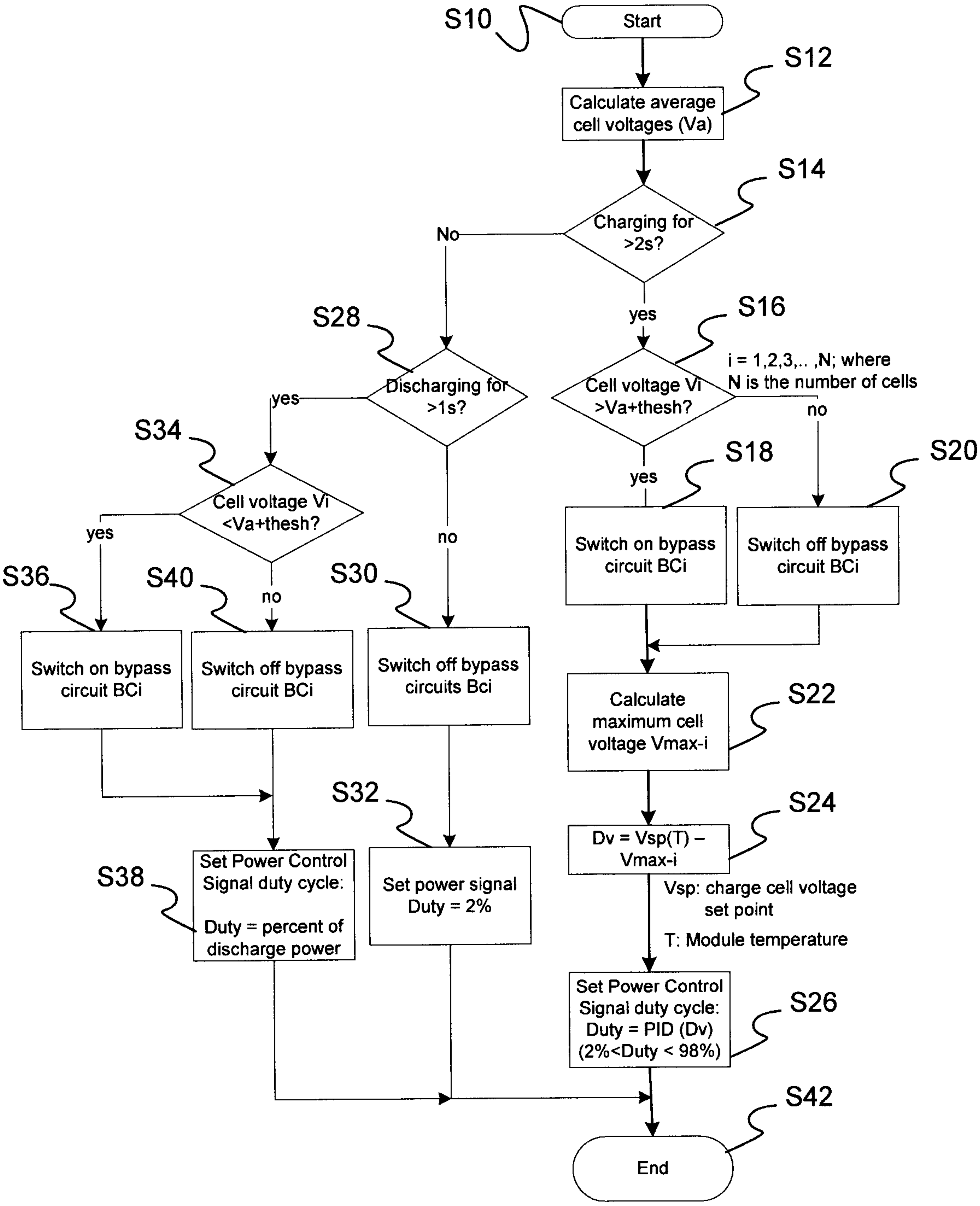

S10
Start
S12
Calculate average cell voltages (Va)
S14
Charging for >2s?
No
yes
S16
i = 1,2,3,.. ,N; where N is the number of cells
Cell voltage Vi >Va+thesh?
no
yes
S18
Switch on bypass circuit BCi
S20
Switch off bypass circuit BCi
S22
Calculate maximum cell voltage Vmax-i
S24
Dv = Vsp(T) – Vmax-i
Vsp: charge cell voltage set point
T: Module temperature
S26
Set Power Control Signal duty cycle: Duty = PID (Dv) (2%<Duty < 98%)
S42
End
S28
Discharging for >1s?
yes
no
S34
Cell voltage Vi <Va+thesh?
yes
no
S36
Switch on bypass circuit BCi
S40
Switch off bypass circuit BCi
S30
Switch off bypass circuits Bci
S32
Set power signal Duty = 2%
S38
Set Power Control Signal duty cycle: Duty = percent of discharge power

FIG. 3

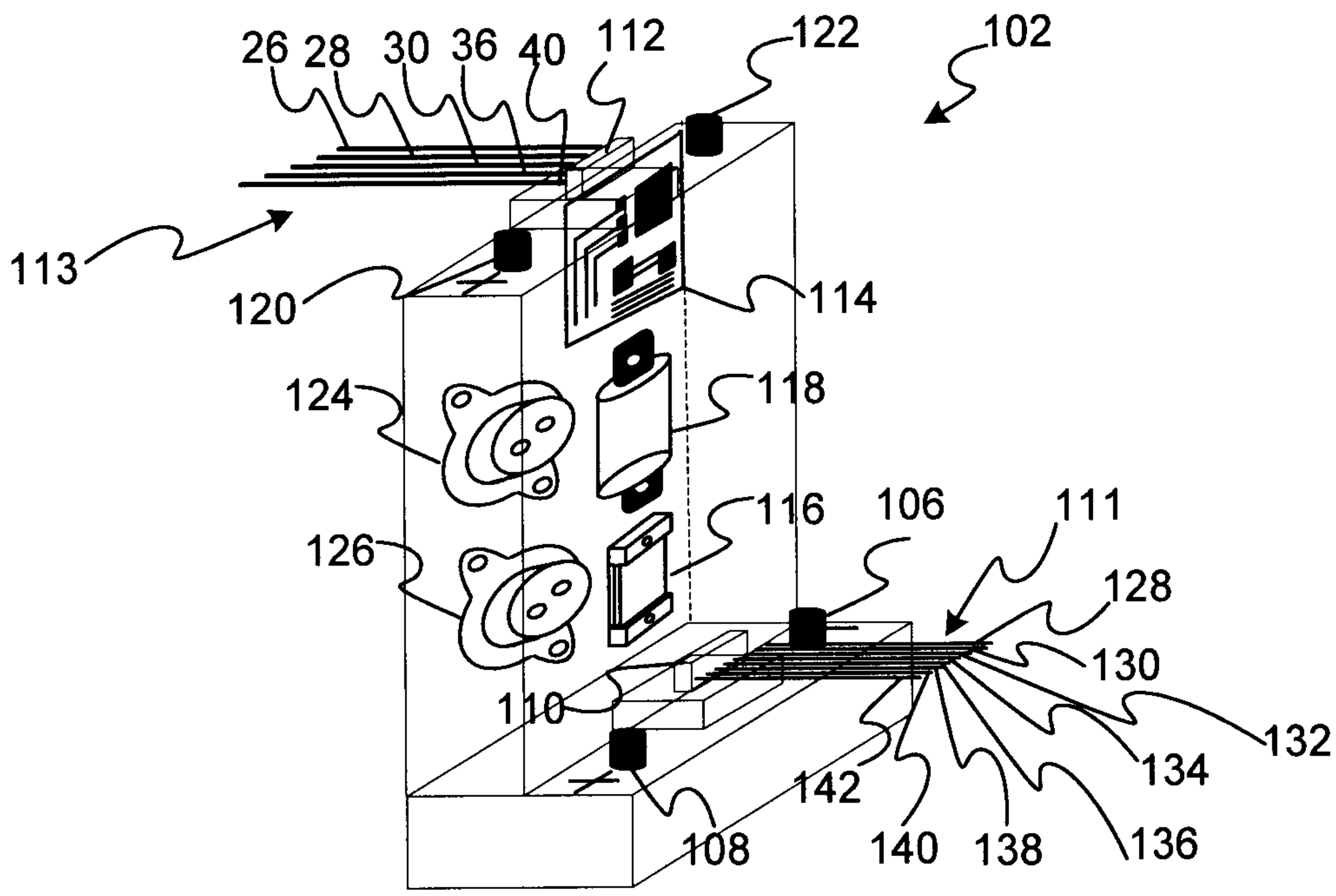

26
28
30
36
40
112
122
102
113
120
114
124
118
126
116
106
111
128
130
110
132
134
142
108
140
138
136

FIG. 4

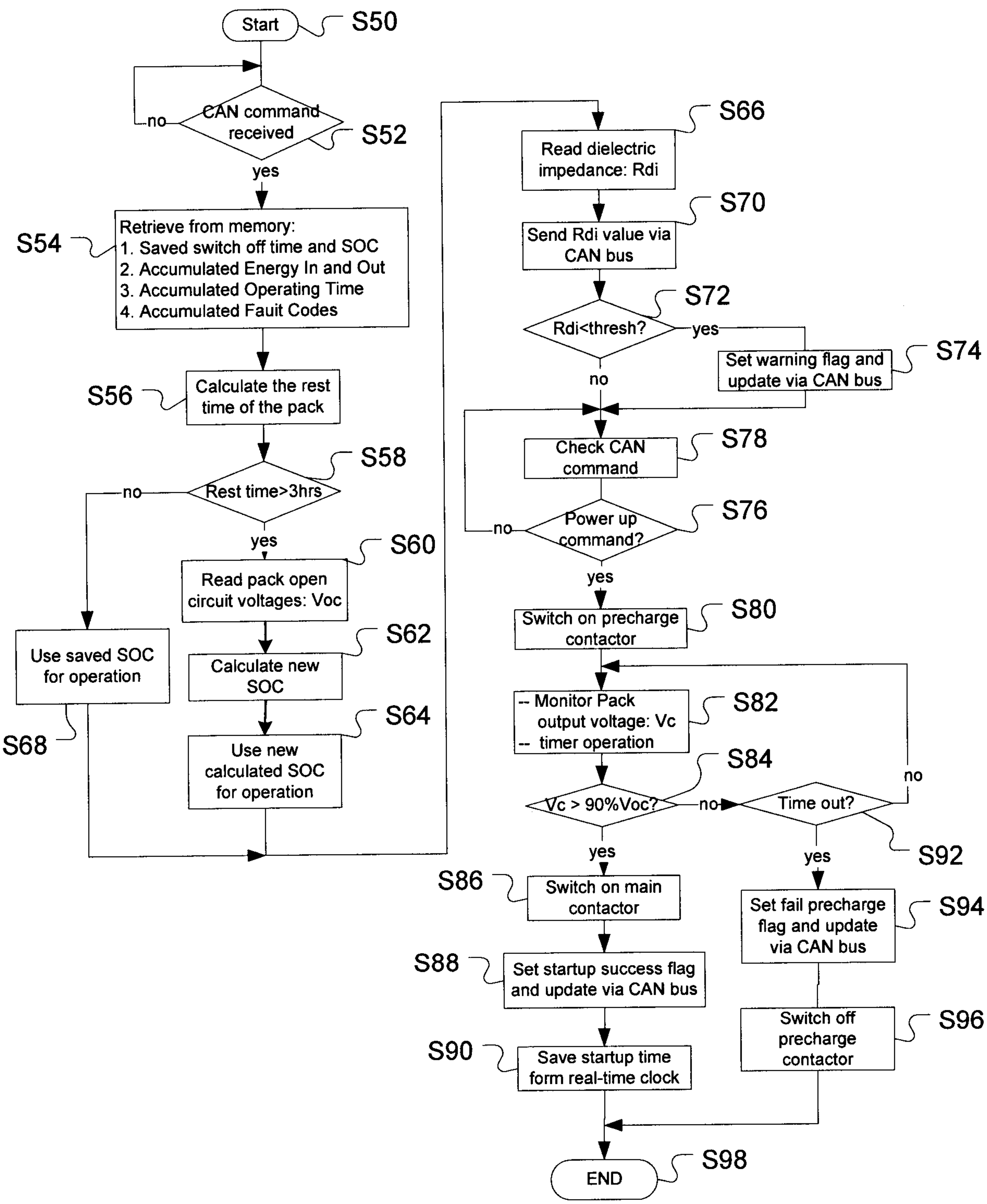

Start
S50
CAN command received
no
yes
S52
S54
Retrieve from memory:
1. Saved switch off time and SOC
2. Accumulated Energy In and Out
3. Accumulated Operating Time
4. Accumulated Fault Codes
S56
Calculate the rest time of the pack
S58
Rest time>3hrs
no
yes
S60
Read pack open circuit voltages: Voc
S62
Calculate new SOC
S64
Use new calculated SOC for operation
Use saved SOC for operation
S68
S66
Read dielectric impedance: Rdi
S70
Send Rdi value via CAN bus
S72
Rdi<thresh?
yes
no
Set warning flag and update via CAN bus
S74
Check CAN command
S78
Power up command?
S76
no
yes
Switch on precharge contactor
S80
-- Monitor Pack output voltage: Vc
-- timer operation
S82
S84
Vc > 90%Voc?
no
Time out?
no
S92
yes
yes
Switch on main contactor
S86
Set startup success flag and update via CAN bus
S88
Save startup time form real-time clock
S90
Set fail precharge flag and update via CAN bus
S94
Switch off precharge contactor
S96
END
S98

FIG. 5

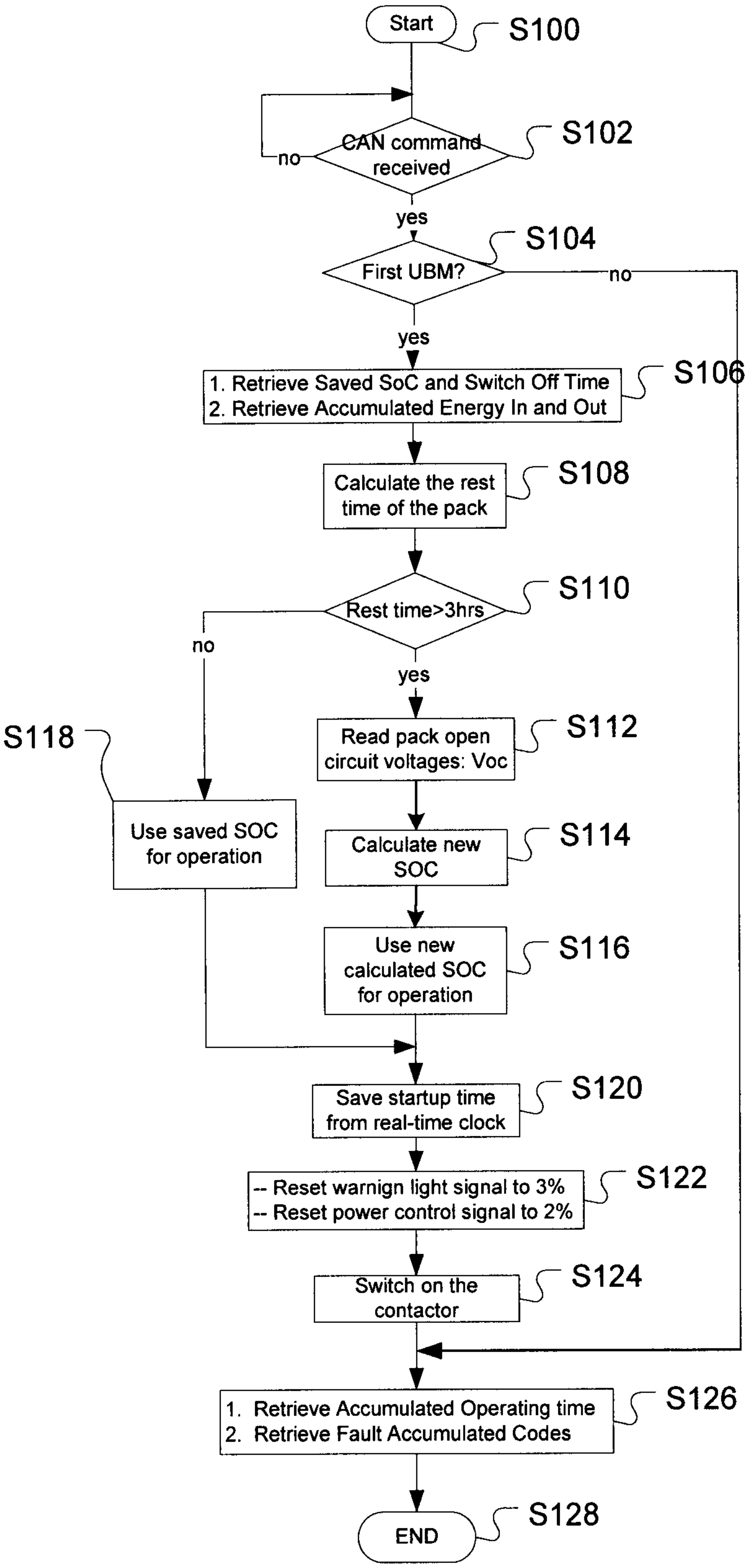
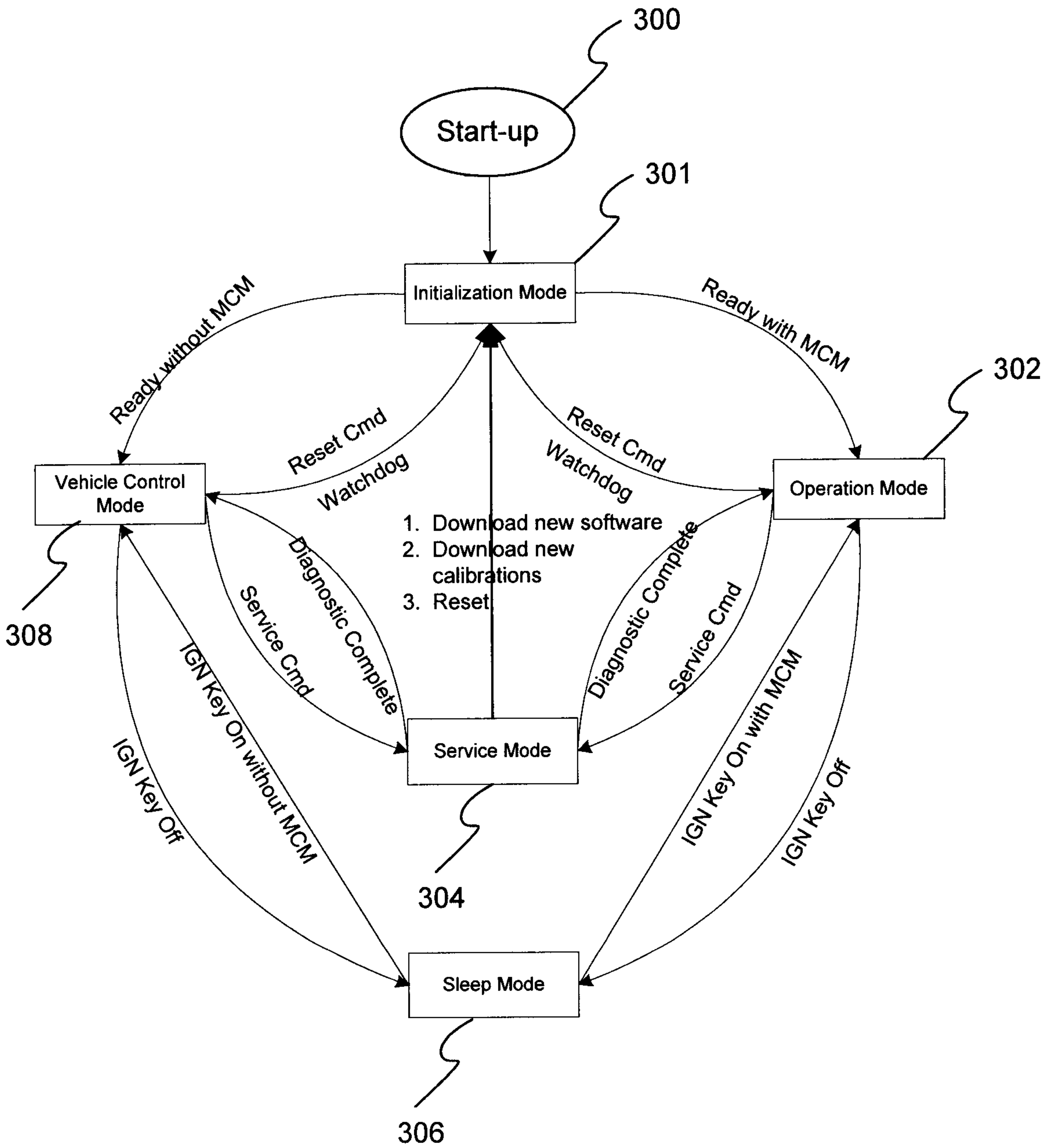

Start
S100
CAN command received
S102
no
yes
First UBM?
S104
no
yes
1. Retrieve Saved SoC and Switch Off Time
2. Retrieve Accumulated Energy In and Out
S106
Calculate the rest time of the pack
S108
Rest time>3hrs
S110
no
yes
Read pack open circuit voltages: Voc
S112
S118
Use saved SOC for operation
Calculate new SOC
S114
Use new calculated SOC for operation
S116
Save startup time from real-time clock
S120
-- Reset warnign light signal to 3%
-- Reset power control signal to 2%
S122
Switch on the contactor
S124
1. Retrieve Accumulated Operating time
2. Retrieve Fault Accumulated Codes
S126
END
S128

FIG. 6



300
Start-up
301
Initialization Mode
Ready without MCM
Ready with MCM
302
Vehicle Control Mode
Operation Mode
Reset Cmd
Watchdog
Reset Cmd
Watchdog
1. Download new software
2. Download new calibrations
3. Reset
308
Diagnostic Complete
Service Cmd
Diagnostic Complete
Service Cmd
Service Mode
IGN Key On without MCM
IGN Key Off
IGN Key On with MCM
IGN Key Off
304
Sleep Mode
306

FIG. 7

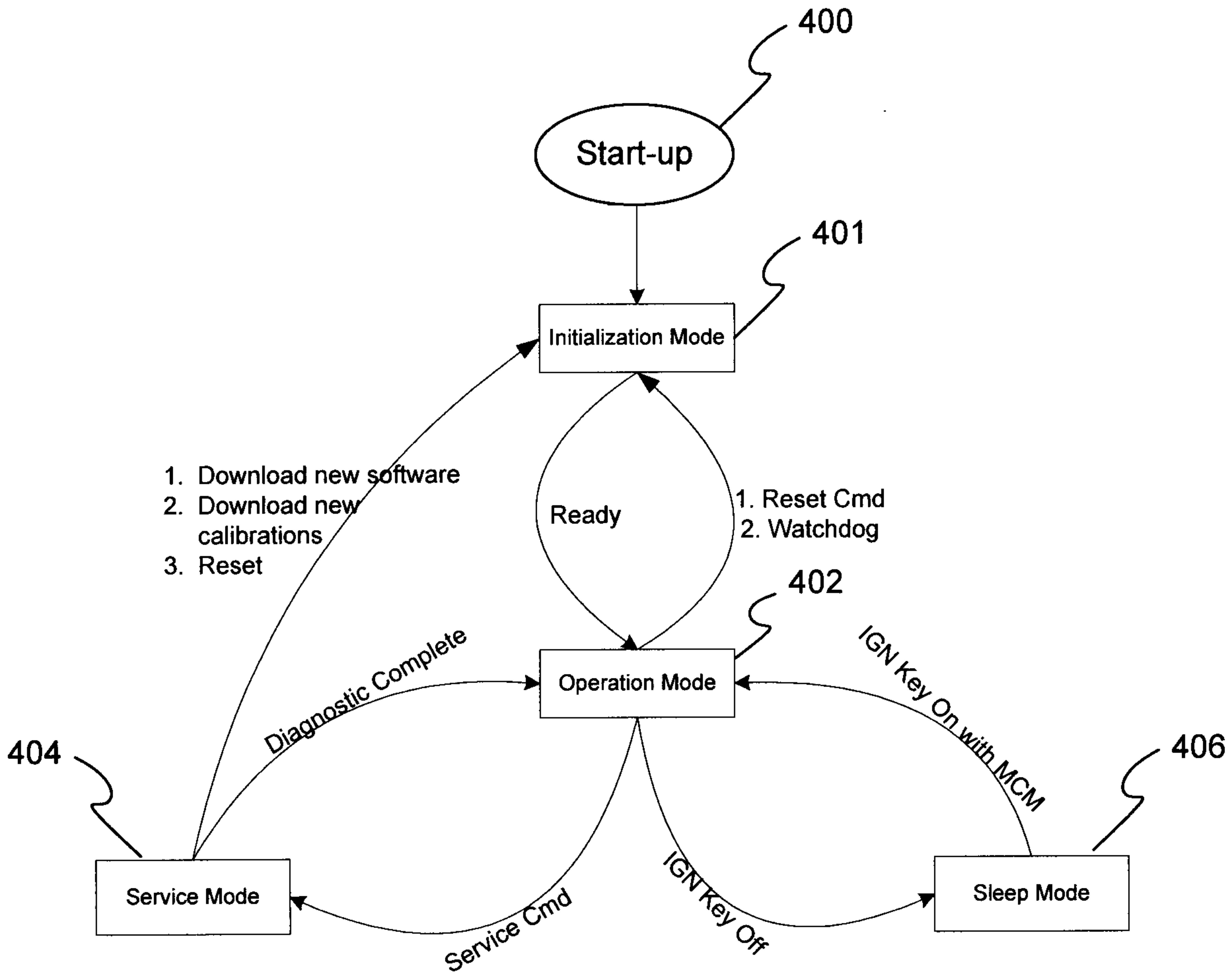

400
Start-up
401
Initialization Mode
1. Download new software
2. Download new calibrations
3. Reset
Ready
1. Reset Cmd
2. Watchdog
402
Diagnostic Complete
Operation Mode
IGN Key On with MCM
404
406
Service Mode
Sleep Mode
Service Cmd
IGN Key Off

FIG. 8

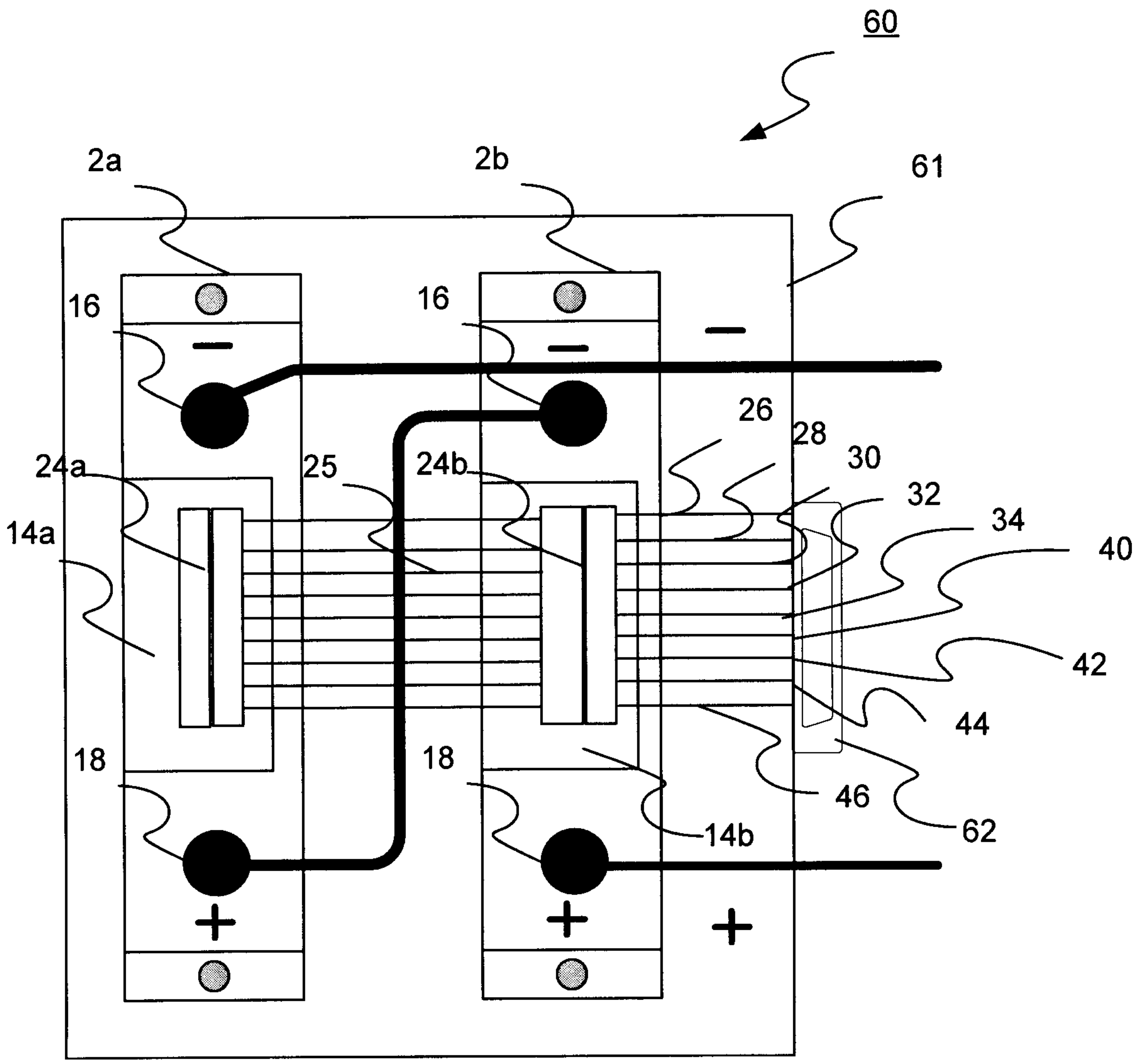

60
2a
2b
61
16
16
24a
25
24b
26
28
30
32
34
40
14a
42
44
18
18
46
14b
62

FIG. 9

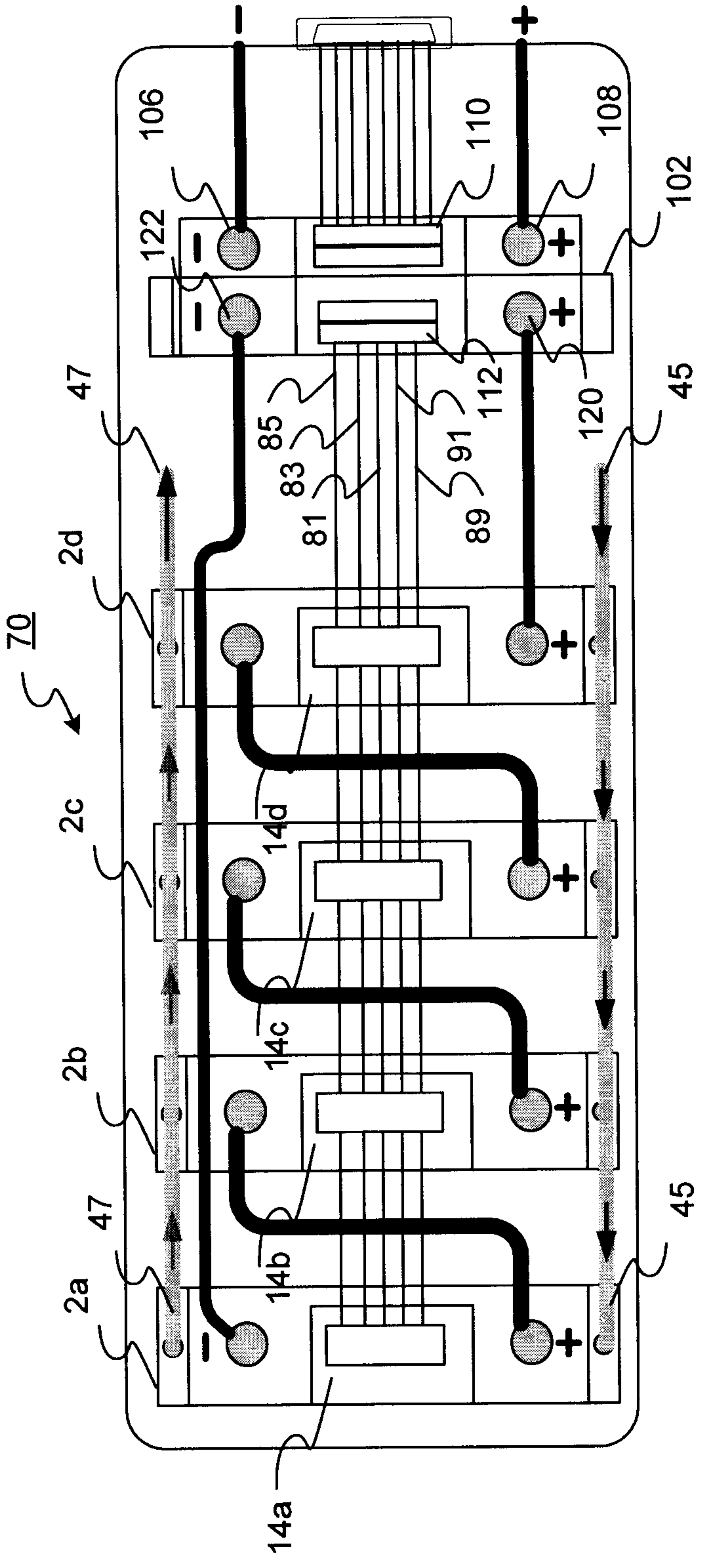

70
106
110
108
102
122
120
112
85
83
81
91
89
47
45
2a
2b
2c
2d
14a
14b
14c
14d

FIG. 10

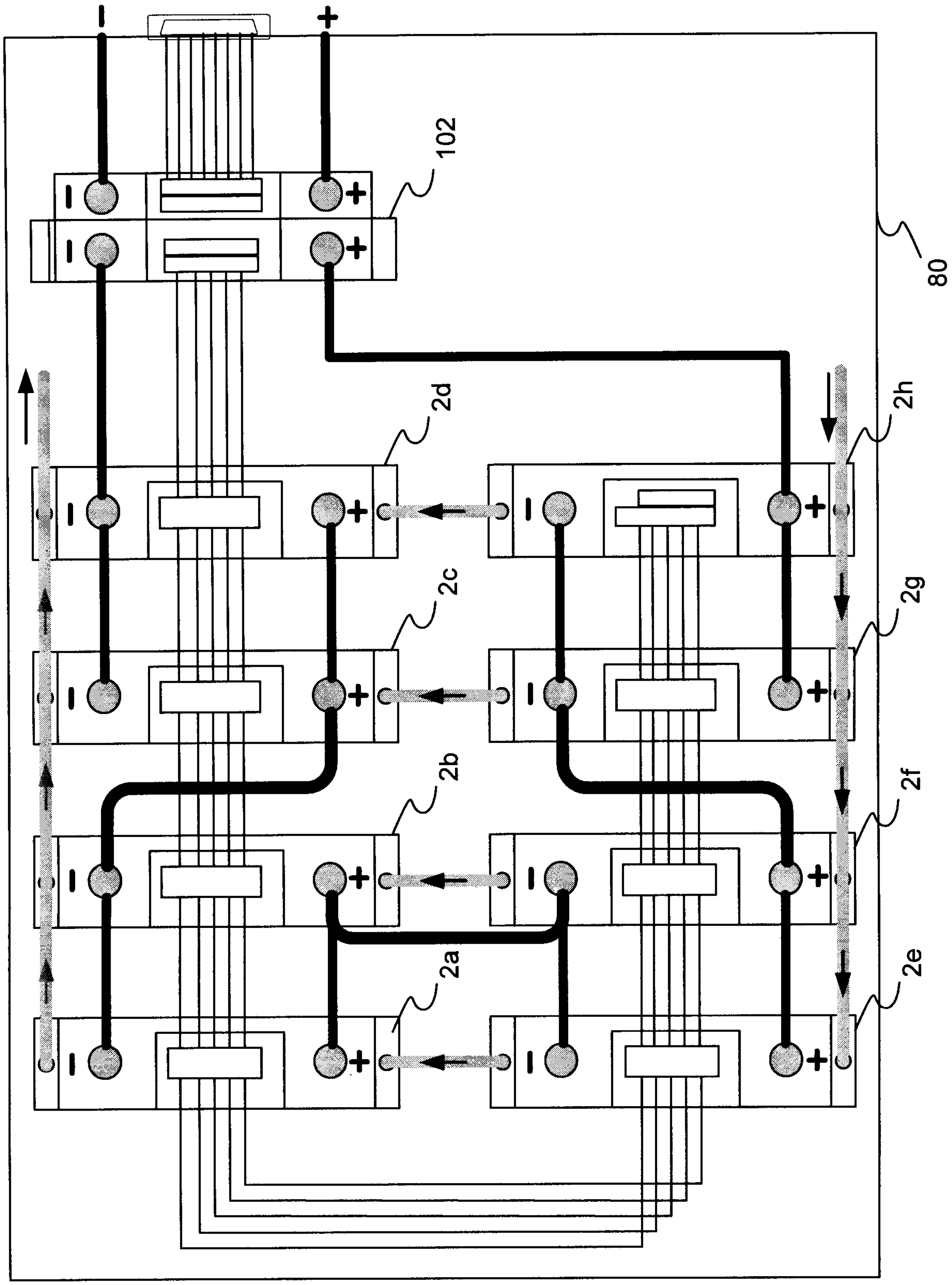


FIG. 11

37
25
Vign
W. Light
PRND
39
41
Vbat
Key
Cluster
35
3
Vign
Vbat
CAN BUS
29
Controller
27
Enable Inv.
Enable Conv.
Enable PS
Vign
2a
2b
2c
2d
2e
1a
47
102
7
50Ah/24V
50Ah/24V
50Ah/24V
50Ah/24V
50Ah/24V
MCM
CAN BUS
29
Vign
Inverter
9
15
13
Traction
Motor
11
13
15
51
7
Vbat
5
Charger
220VAC
21
48V/14V
Converter
Vbat
12V
23
Power
steering
Pump
Power
Steering
Motor
519
517
Li Battery Pack: 50Ah/120VDC
45
Safety
Vign
43
Pump