



(86) Date de dépôt PCT/PCT Filing Date: 2015/04/02
(87) Date publication PCT/PCT Publication Date: 2016/04/07
(85) Entrée phase nationale/National Entry: 2017/03/31
(86) N° demande PCT/PCT Application No.: US 2015/024027
(87) N° publication PCT/PCT Publication No.: 2016/053385
(30) Priorité/Priority: 2014/10/03 (US62/059,461)

(51) Cl.Int./Int.Cl. *H02J 7/00* (2006.01)
(71) Demandeur/Applicant:
ELITISE LLC, US
(72) Inventeurs/Inventors:
POULIS, SPIRO, US;
BEGLIAROV, SERGEI N. BEGLIAROV, US;
ZAKHARYAN, KAGUM G., US
(74) Agent: JOHNSTON LAW

(54) Titre : ARCHITECTURE DE MODULE DE BATTERIE A EXTENSIBILITE HORIZONTALE ET VERTICALE
(54) Title: BATTERY MODULE ARCHITECTURE WITH HORIZONTAL AND VERTICAL EXPANDABILITY

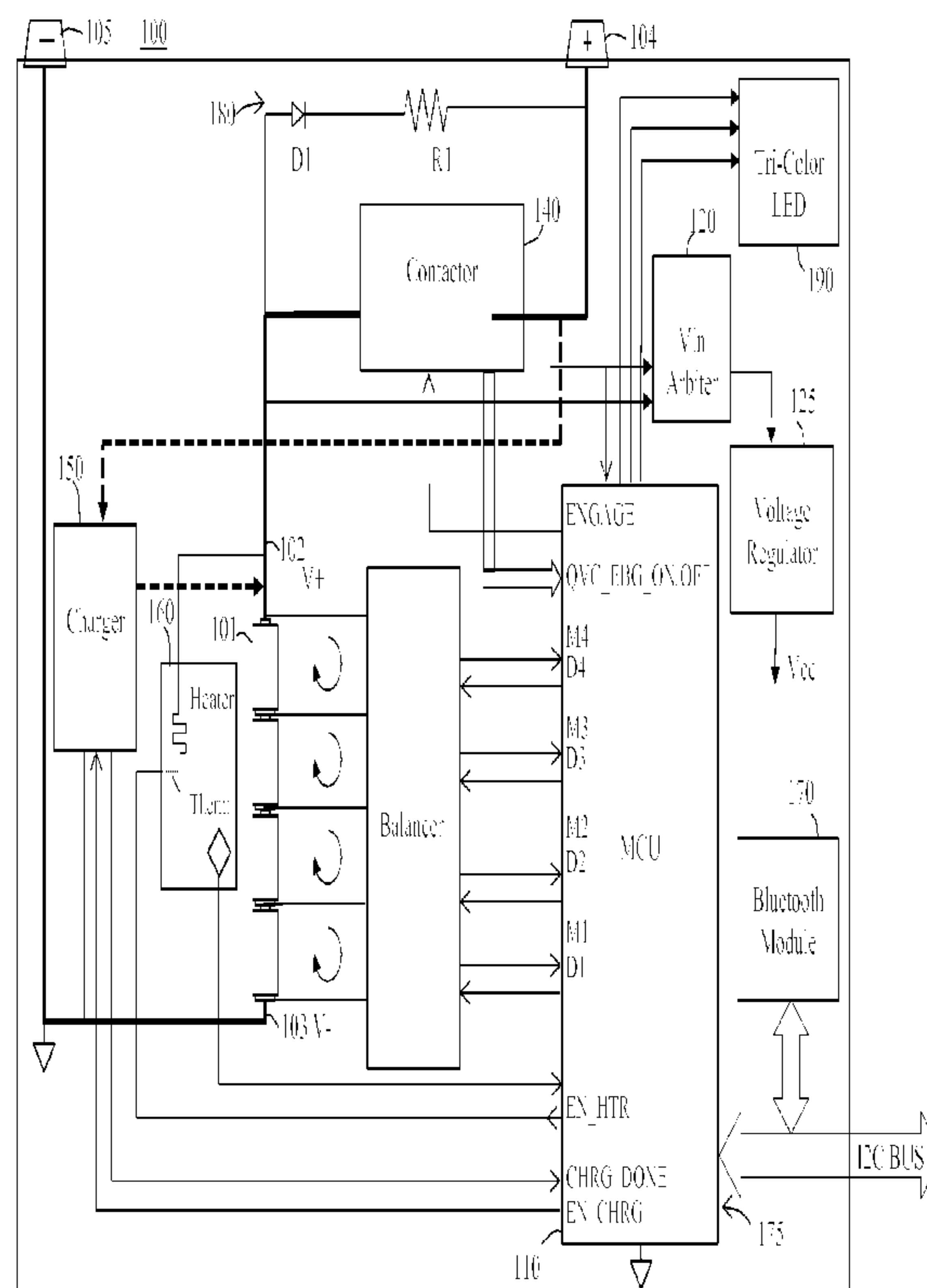


FIG. 1

(57) **Abrégé/Abstract:**

A battery module architecture including a plurality of battery cells coupled electrically in series and having a combined battery potential proportional to the combined sum of the battery cells is controlled by microcontroller to balance battery cell voltages by a battery cell voltage balancer having a discharging circuit and a plurality of differential conductive connections each respectively coupled to positive and negative terminals of one of the battery cells.



(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau(43) International Publication Date
7 April 2016 (07.04.2016)(10) International Publication Number
WO 2016/053385 A1(51) International Patent Classification:
H02J 7/04 (2006.01)(21) International Application Number:
PCT/US2015/024027(22) International Filing Date:
2 April 2015 (02.04.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/059,461 3 October 2014 (03.10.2014) US(71) Applicant: **ELITISE LLC** [US/US]; 1668 S. Research Loop #332, Tucson, AZ 85710 (US).(72) Inventors: **POULIS, Spiro**; 9885 East Murchison Place, Tucson, AZ 85748 (US). **Begliarov, Sergei, N. Begliarov**; 6261 E Placita Aspecto, Tucson, AZ 85750 (US). **ZAKHARYAN, Kagum, G.**; 8860 East Appomattox Street, Tucson, AZ 85710 (US).(74) Agent: **CAMPILLO, Michael, F.**; Venjuris P.c., 1938 E. Osborn Rd., Phoenix, AZ 85016 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

[Continued on next page]

(54) Title: BATTERY MODULE ARCHITECTURE WITH HORIZONTAL AND VERTICAL EXPANDABILITY

(57) Abstract: A battery module architecture including a plurality of battery cells coupled electrically in series and having a combined battery potential proportional to the combined sum of the battery cells is controlled by micro-controller to balance battery cell voltages by a battery cell voltage balancer having a discharging circuit and a plurality of differential conductive connections each respectively coupled to positive and negative terminals of one of the battery cells.

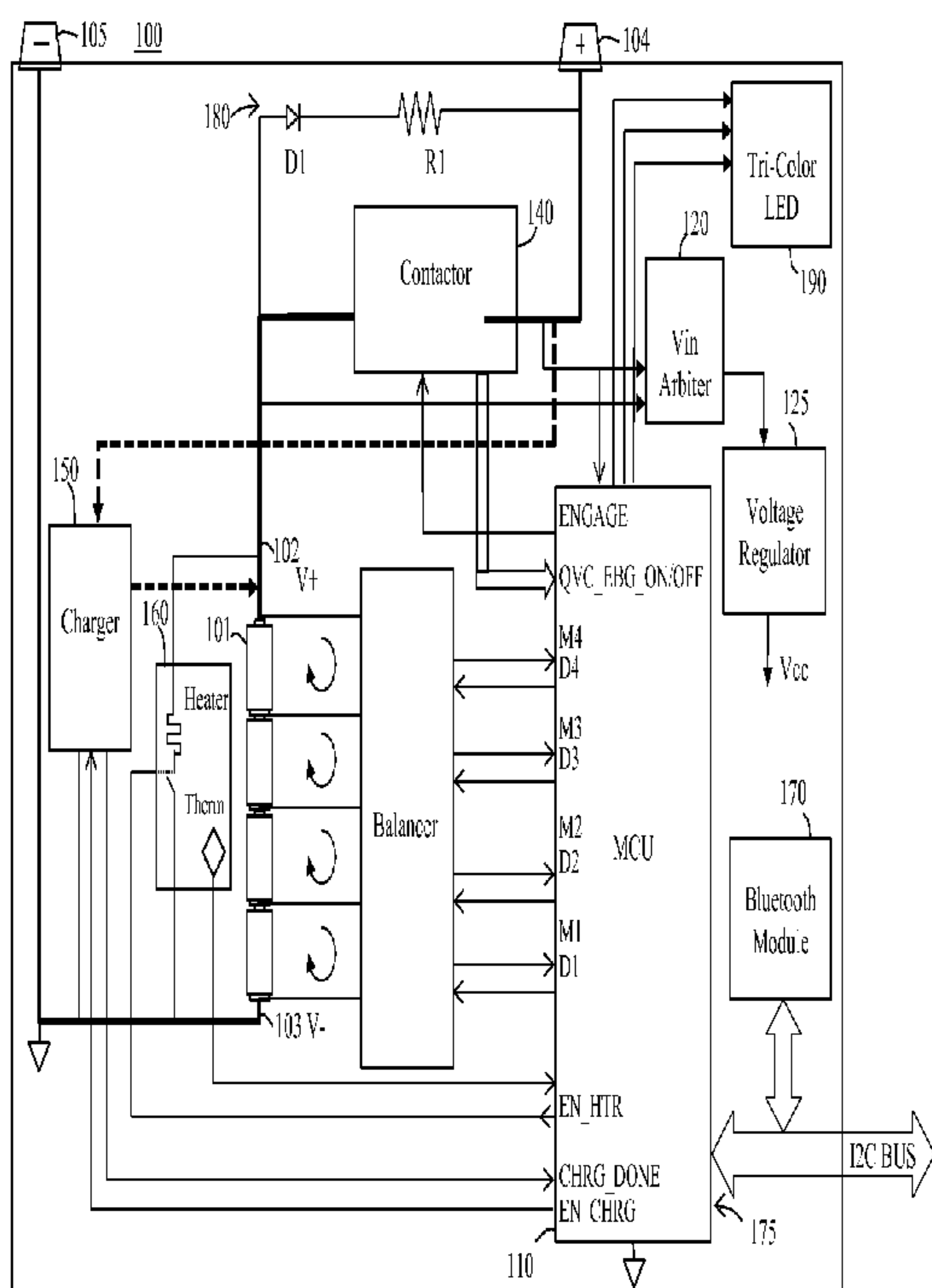


FIG. 1

WO 2016/053385 A1

— of inventorship (Rule 4.17(iv))

— with amended claims and statement (Art. 19(1))

Published:

— with international search report (Art. 21(3))

BATTERY MODULE ARCHITECTURE WITH HORIZONTAL AND VERTICAL EXPANDABILITY

FIELD OF THE INVENTION

[01] The present invention relates to battery module architectures that facilitate use of battery chemistries, such as lithium-based batteries, that are intended as replacements for lead-acid based batteries. Additionally, the present invention relates to battery architectures that facilitate creation of an aggregate battery module that is comprised of a plurality of independently housed battery modules.

BACKGROUND OF THE INVENTION

[02] Lithium based batteries have grown in popularity over lead-acid batteries due to their relatively small size and weight compared to lead-acid batteries of similar capacity. Although common in small devices such as cellular phones and cameras, increasingly lithium based batteries are used to power larger loads such as electric cars.

[03] An enclosed battery module, such as those used to start internal combustion engines, typically consist of multiple battery cells coupled together to meet the power requirements of an application. For example, in a battery application requiring 12 VDC, a battery module may consist of four battery cells of at least 3 volts electrically coupled together in series to sum the cell voltages for the battery module. For such applications, lead acid battery cells may be “stacked” or connected electrically in series by a simple conductor to sum the individual cell voltages to meet the voltage requirement.

[04] Lithium-based battery modules may also comprise a stack of battery cells for applications such as internal combustion engines. Lithium battery cells, however require charging in a prescribed manner ensure safe battery operation and also preserve battery cell life. Lithium-based battery modules for example commonly include circuitry that compares and balances the charges on each Lithium battery cells in a battery module to prevent overcharge of battery cells. One solution includes battery cell balancing circuitry that is coupled to the individual battery cells and that permits controlled discharge of individual battery cells. During charging operations, the battery cell balancing circuitry samples and compares each of the individual battery cell voltages to each of the other battery cell voltages (or a reference voltage) and balances or discharges individual battery cells having charges that exceed the lowest charged battery cell. This technique typically includes measuring each battery cell charge and producing corrective charging feedback in a control loop that causes a charge or discharge of individual battery cells to match the charge on other cells.

[05] Additional components such as voltage regulators, battery chargers, and communication transceivers may also be included to enable practical use of lithium-based battery modules. There remains a need however for improvements in battery module architectures and management strategies to facilitate use of lithium-based batteries chemistries in applications where lead-acid based battery use currently dominates.

SUMMARY OF THE INVENTION

[06] The present disclosure includes improvements to battery architectures to enhance the functionality, safety and battery life of batteries. The resulting battery architecture facilitates the use of battery chemistries, such as Lithium, in battery modules intended as substitutes for lead-acid based battery modules.

[07] The present disclosure includes a battery module architecture comprising multi-cell battery control circuit. The battery module generally includes a plurality of battery cells coupled electrically in series and having a combined battery potential proportional to the combined sum of the battery cells. The circuit may include a microcontroller, and a battery cell voltage balancer having a discharging circuit and a plurality of differential conductive connections each respectively coupled to positive and negative terminals of one of the battery cells. The balancer may have at least one cell balancing output and at least one cell balancing input to transmit and receive cell voltage balancing information to and from the microcontroller, respectively. A battery charger may be coupled to the series-coupled battery cells and the microcontroller. A contactor may be coupled between the combined battery potential and the battery positive terminal and have a control input coupled to the microcontroller. A communications link may be connected to the microcontroller to enable communication of the battery module information to one or more remote transceivers outside of the battery housing.

[08] The battery cell voltage balancer may include at least one but preferably a number of battery cell voltage sampling circuits and discharge circuits equivalent to the number of battery cells. The discharge circuits may draw discharge current from the respective battery cell to match battery cell voltages within a battery module and analog-to-digital converters may sample the voltage in each coupled battery cell and output the sampled voltages to the microcontroller for analysis.

[09] A thermistor and heater may be coupled to the microcontroller and positioned in thermal communication with the plurality of battery cells to both measure and affect the temperature of the battery cells based on input from the microcontroller.

[10] A contactor may be electrically coupled in series between the combined battery potential and the positive battery terminal. The contactor may have a closed state that permits current to

flow from the combined battery potential and the positive battery terminal, and an open state that prohibits current to flow from the combined battery potential and the positive battery terminal. The contactor may include a bi-directional current sensing circuit that includes a current sense element connected to sense the current flowing at the positive battery terminal. The bi-directional current sensing circuit may include a current-to-voltage converter that produces at least one output that is representative of the polarity of the current flowing through the current sense element. The current-to-voltage converter may for example produce both digital and analog outputs. Moreover, at least one output or outputs are coupled to the microcontroller. The battery module may include a low power current path coupled parallel to the contactor to power engine computers and the like when the contactor is in the open state.

[11] Additional aspects of the disclosure include a method of managing a battery module having a plurality of battery cells, comprising sampling the voltages on the plurality of battery cells, storing the sampled voltages in memory, comparing the sampled voltages against each other to determine a battery cell having a lowest sampled voltage, and discharging the battery cells that have voltages greater than the lowest sampled voltage until the battery cells that have voltages greater than the lowest sampled voltage have substantially the same voltage as the battery cell having a lowest sampled voltage.

[12] The method may also or alternately include sensing the magnitude of the current flowing from the positive terminal of the battery module to determine if the magnitude of the current exceeds a reference current and activating a contactor to open the contactor and create an open circuit between the plurality of battery cells and the positive battery terminal if the magnitude of the current exceeds the reference current. The method may also include charging the plurality of battery cells from the charger if the current exceeds the reference current. The method may include also reading the temperature of the plurality of battery cells, comparing the temperature of the plurality of battery cells to a reference temperature, and charging the plurality of battery cells from the charger if the temperature of the plurality of battery cells exceeds the reference temperature. The method may also include heating the plurality of battery cells if the temperature of the plurality of battery cells is less than the reference temperature.

[13] The method may alternately include sensing the magnitude of the voltage at the positive terminal of the battery module to determine if the voltage exceeds a reference voltage and activating the contactor to open the contactor and create an open circuit between the plurality of battery cells and the positive battery terminal if the magnitude of the voltage exceeds the reference voltage.

[14] The battery module may also include a communication link coupled to a receiver external to the battery module, and the method further include sensing an original accumulated battery cell voltage, detecting each occurrence wherein the accumulated battery cell voltage decreases at least twenty percent below the original accumulated battery cell voltage, and transmitting via the communication link an indication of each occurrence wherein the accumulated battery cell voltage decreased at least twenty percent below the original accumulated battery cell voltage to the receiver. The method may further include detecting each subsequent occurrence wherein the accumulated battery cell voltage increases above the original accumulated battery cell voltage, detecting each subsequent occurrence wherein the accumulated battery cell voltage decreases to a voltage that is within five percent of the original accumulated battery cell voltage, and transmitting via the communication link an indication of each occurrence wherein the accumulated battery cell voltage decreases to a voltage that is within five percent of the original accumulated battery cell voltage to the receiver.

[15] The method may also be used in an aggregate battery module wherein the battery module comprises a master battery module of a plurality of battery modules and each of the plurality of battery modules has a plurality of battery cells. The method may further include sampling the voltages on the plurality of battery cells in each of the other plurality of battery modules, storing the sampled voltages on the plurality of battery cells in each of the other plurality of battery modules in memory, communicating the voltages sampled in each of the other plurality of battery modules to the master battery module, comparing the sampled voltages in the plurality of battery modules to determine a battery module and a battery cell within having a lowest sampled voltage, and discharging the battery cells in all of the battery modules that have battery cell voltages greater than the lowest sampled voltage until the battery cells in the plurality of battery cells have substantially the same voltage as the lowest sampled battery cell voltage. The method to create an aggregate battery module may include coupling a subset of the plurality of battery modules electrically in series or in parallel to achieve alternate power capabilities.

[16] The method may also be used with an aggregate battery module wherein the battery module comprises a master battery module of a plurality of battery modules, each of the plurality of battery modules has a plurality of battery cells having an accumulated battery voltage coupled to a positive battery terminal through a contactor. The method including opening at least one of the contactors at a time so that N-1 or fewer contactors are closed during battery operations.

[17] An aggregate battery according to the disclosure may contain a plurality of battery modules each including a positive battery terminal and a negative battery terminal. The plurality of battery cells may be electrically coupled in series to create an accumulated battery cell voltage that is applied to the positive battery terminal. A battery cell balancer may be coupled to the plurality of battery cells and a microcontroller coupled to the battery cell balancer. A communications link may be coupled to the microcontroller. A first subset of the plurality of battery modules may have the positive battery terminals coupled together and the negative battery cells coupled together and the communications link of each of the first subset wirelessly coupled to the communication link in at least one of the other battery modules in the first subset.

[18] The aggregate battery may alternately include a second subset of the plurality of battery modules having the positive battery terminals coupled together and the negative battery cells coupled together. The communications link of each of the second subset may be wirelessly coupled with the communication link in at least one of the other battery modules. The negative terminals of the second subset may be coupled to the positive battery terminals of the first subset and each of the second subset of the plurality of battery modules may be wirelessly coupled with the communication link in one of the battery modules in the first subset.

BRIEF DESCRIPTION OF THE DRAWINGS

[19] **FIG. 1** illustrates a battery module **100** incorporating aspects of the present disclosure;

[20] **FIG. 2** illustrates an aggregate battery module **200** comprising a plurality of battery modules **100**, wherein a first subset of battery modules **100** are electrically coupled in parallel to each other, and second subset of battery modules **100** are electrically coupled in parallel to each other, a third subset of battery modules **100** are electrically coupled in parallel to each other, the first subset of battery modules coupled in series with the second subset of battery modules, and the third subset of battery modules connected in series with the second subset of battery modules;

[21] **FIG. 3** shows a block diagram of the bi-directional current sensor **300** that includes a current-sense element (e.g. a current-sense resistor **320**) and a current-to-voltage converter **310** with an analog output **350**, a digital output **360** and a digital input; and

[22] **FIG. 4** illustrates the change in battery module **100** voltage over time due to a start event of an internal combustion engine.

DESCRIPTION OF PREFERRED EMBODIMENTS

[23] A block diagram of a battery module **100** implementing features of the invention is illustrated in **FIGS. 1-3**. The battery module **100** embodiment comprises a physically sealed

battery based power source including a plurality of Lithium based battery cells **101** operatively coupled to subsystems having distinct functions that operate together to provide safe and reliable power from the battery module **100**. See **FIG. 1**. The battery module **100** is enclosed within a substantially rectangular plastic battery housing and power from the battery module **100** is accessed through a positive battery terminal **104** and a negative battery terminal **105** that each penetrate and conduct electrical current to and from the battery module **100**.

[24] **FIG. 1** illustrates an application of the invention wherein the battery cells **101** are coupled electrically to each other in series or “stacked” to accumulate or sum the individual battery cell voltages and create the accumulated battery module voltage **102** that is equivalent to the sum of each of the battery cell **101** minus small power losses from the individual battery cell terminals or any conductive connectors between or leading to and from the first and last battery cells **101**. Balancing of the voltages on the battery cells **101** is accomplished using the battery cell balancer **130** and the microcontroller **110**.

[25] Battery cell **101** balancing comprises measurement, comparison and controlled discharge of selected battery cells **101** to closely balance or equalize the charges on each battery cell **101**. Measurement of each battery cell **101** may be accomplished by coupling conductive voltage sensing inputs of a battery cell balancer **130** to the terminals of each battery cell **101** and controlling active components in the battery cell balancer **130** to correctively discharge any single battery cell **101** that has a sensed voltage greater than another battery cell **101** or another reference voltage provided to or within the balancer **130**. Accordingly, the balancer **130** comprises a plurality of conductive connections that are respectively coupled to the positive and negative terminals of the individual battery cells **101** and allow a flow of discharge current from each battery cell **101**. The illustrated battery cell balancer **130** is implemented with a plurality of analog-to-digital (A/D) converters with the inputs of each A/D converter coupled to one of the terminals of each battery cell **101**. See **FIG. 1**. In the illustrated battery module **110** the inputs of each A/D converter comprise a first input and a second input that are connected to the negative terminal and positive terminal of each battery cell **101**, respectively, to enable sampling or measurement of the voltage existing on each battery cell **101**. The battery cell balancer **130** is coupled to a microcontroller **110** that compares the voltages on each of the battery cells **101** and directs corrective discharge feedback to the balancer **130** according to programming within the microcontroller **110**.

[26] Battery cell **101** voltages sampled from the battery cell balancer **130** are coupled to the microcontroller **110** for comparison and subsequent correction if necessary. Particularly, the outputs of the A/D converters in the cell balancer **130** are each coupled to an input/output port

on the microcontroller **110** that is programmed to read the digital outputs from the A/D converters of the cell balancer **130** (i.e. “M4”) into microcontroller memory. The microcontroller is programmed to compare the cell voltages and output corrective discharge feedback (i.e. “D3”) that is coupled to the cell balancer **130** and controls the operation of a discharging circuit that may include active circuitry configured to discharge any individual battery cell **101** in the stack having excessive charge or exceeding a reference voltage. As one example, the corrective discharge feedback is applied to the gate of a Field Effect Transistor (FET) wherein the drain and source are coupled across the positive and negative terminals of the battery cell, respectively and the corrective discharge feedback causes the FET to drain current from the battery cell that requires discharging. Electrical isolation of the cell balancer **130** discharge circuitry may be provided by opto-couplers coupled between the discharge feedback from the microcontroller **110** and the cell balancer **130** discharge circuitry.

[27] A thermistor and heater **160** is positioned in the thermal environment adjacent the battery cells **101** to both measure and affect battery cell **101** temperatures. The heater **160** comprises a resistive heating element that is coupled between the accumulated battery module voltage **102** and system ground. The thermistor (“Therm”) may be coupled to the microcontroller **110** via an analog-to-digital converter to sample current measurements, which may be read-in by the microcontroller **110** to determine the temperature of the thermal environment adjacent the battery cells **101**. As one example, the microcontroller **110** programming reads the thermistor measurements into memory and compares the measurements to internal reference values to determine whether the battery cells **101** are too cold to be safely charged and the heater **160** should be turned on to increase the temperature of the battery cell **101** environment. The microcontroller **110** can be programmed to turn on the heater **160** if the ambient temperature is below a threshold temperature (e.g. -10 degrees Celsius). The microcontroller **110** may turn on the heater **160** by closing a switch in the current path of the resistive heating element using a heater enable output (“EN_HTR”). Closing the switch allows current to flow through the resistive heating element and heat the environment adjacent the battery cells **101**. Conversely, the microcontroller **110** may disable the heater **160** by opening the switch in the path of the resistive heating element.

[28] A solid-state contactor **140** is electrically coupled in series between the battery cells **101** and the positive battery terminal **104** and has a CLOSED state and an OPEN state. When in the CLOSED state the contactor **140** allows current flow between the accumulated battery cell voltage **102** and the positive battery terminal **104**. Conversely, when in the OPEN state the contactor **140** presents an open circuit or near infinite impedance between the accumulated

battery cell voltage **102** and the positive battery terminal **104**. The contactor **140** is coupled to or combined with a bi-directional current sensing circuit **300** to sense the magnitude and polarity of current flow to and from the battery module **100**, which is indicative of engine or battery module **100** operating states and/or state changes.

An example of a bi-directional current sensing circuit **300** is illustrated in **FIG. 3** and comprises a bi-directional current sense current-to-voltage converter (“I-V Converter”) **310** that reproduces or amplifies the voltage differential produced by the current flowing through a current sense element (e.g. a current-sense resistor **320**) that is electrically coupled in series between the positive battery terminal **104** and the engine cable that supplies power to the engine. The gain of the I-V Converter **310** may be programmably increased or decreased based on input from the microcontroller **110** to accommodate the current-use characteristics of alternate battery applications. The bi-directional current sensing circuit **300** may include an analog output **350** that outputs a proportional representation of the current flowing through the current sense element, which may be coupled to the microcontroller **110** via an analog-to-digital converter to enable measurement and capture of on-going current use data. One or more binary or digital outputs **360** may be coupled to the microcontroller **110** to provide output information that is representative of the current flowing through the current sense element. The illustrated bi-directional current sensing circuit **300** includes a two digit binary data/output that is representative of both the magnitude and polarity of the current flowing through the current sense element.

[29] The contactor **140** has a disable input that is coupled to port of the microcontroller **140** (“ENGAGE”) and is used to cause the contactor **140** to change states (i.e. “OPEN”) and cause an open circuit in the path between the accumulated battery cell voltage **102** and the positive battery cell terminal **104**. The OPEN state of the contactor **140** may be useful during programmed management of the battery module **100** or if the battery module **100** is subject to unsafe operating conditions that might damage the battery module **100** components. Unsafe operating conditions that cause the microcontroller **110** to toggle the ENGAGE output and cause an OPEN state of the contactor **140** include threats of both internal and external origin. Examples of internal threats include overcharged or undercharged battery cells **101**, one or more failed or faulty battery cells **101**, or battery cell **101** temperatures outside specified limits while the engine is running (i.e. “ENGINE_ON”). Each of the threats having internal origins can be detected by the microcontroller **110** programming and eliminated. External threats associated with extreme current magnitudes are detected with the bi-directional current sensing circuit **300**.

[30] Over-current conditions created externally to the battery module **100** can be detected and terminated before the battery module **100** is damaged or does damage to other engine components. If for example, the positive battery terminal **104** and negative battery terminal **105** are shorted (or during any other sustained over-current condition), a very large and sustained battery current will result in a sustained relatively large magnitude of current through the current-sense resistor **320** that the bi-directional current sensing circuit **300** will convey to the microcontroller **110** (“OVC”). The microcontroller **110** will immediately toggle the ENGAGE output to cause an OPEN state of the contactor **140** and end the short-circuit (or over-current condition). Similarly, a substantial change in battery current may indicate a significant change in the load impedance that can be detected by the microcontroller **110** and stored in memory or reported to the engine computer or transmitted to remote receivers. Finally, the contactor **140** OPEN state condition can also be selected based upon receipt of interrupts or other commands that are communicated to the microcontroller **110** from a communication **170** that is able to communicate with one or more remote wired or wireless transceivers.

[31] The bi-directional current sensing circuit **300** may also be used under normal battery module **100** operating conditions to detect battery current consumption and engine operating states and state changes. As an example, the start event of an internal combustion engine as initiated by a starter-motor requires a sudden and relatively large inrush current. If the engine is in the OFF state, the contactor **140** is normally in the CLOSED state to allow battery current to flow from the battery module **100** to power a starter-motor for an engine start event. **FIG. 4** illustrates the possible change in battery module voltage, V_{+Bat} , due to an engine start event and followed by an engine stop/off event. Before the engine start event, the battery module **100** produces voltage at the positive battery terminal **104** that is substantially equal to the accumulated battery cell **101** voltages, V_{ACC} . At an engine start event, t_{start} , the start-current flowing from the battery module **100** will be enough to reduce the battery module voltage to less than a programmable reference threshold voltage, V_{thr} , that is less than the original accumulated battery cell voltage, V_{ACC} , and preferably less than about seventy percent of the original accumulated battery cell **101** voltage. The microcontroller **110** programming detects each occurrence when the batter terminal **104** voltage decreases to less than the reference threshold voltage, which may be used internally within the microcontroller **110** as an interrupt (e.g. “IGNITION_ON”) or communicated external to the battery module **100** or both.

[32] After engine start and under normal operating conditions, the battery module **100** will provide current to the engine electrical system until a time, t_{charge} , (exaggerated in the drawing) when the alternator voltage applied to the positive battery terminal **104** just exceeds the

accumulated battery cell voltage, V_{ACC} , and begins to charge the battery cells **101** by current flowing from the engine alternator, through the positive battery terminal **104** and contactor **140**, to the battery cells **101**. The microcontroller **110** programming may detect each occurrence when the battery terminal voltage **104** returns to or exceeds the original accumulated battery cell **101** voltage, V_{ACC} , which occurrences may be used internally within the microcontroller **110** as interrupt (e.g. "ENGINE_ON") or communicated external to the battery module **100** or both. Finally, the engine entering an off state, at t_{off} , results with the voltage at the positive battery terminal **104** decreasing or returning to substantially the same voltage as the original accumulated battery cell **101** voltage, V_{ACC} , and may correspond to an engine off ("ENGINE_OFF") signal/interrupt for the microcontroller **110**.

[33] Charging of the battery cells **101** by the manner described above is allowed provided that the current flowing from the positive battery terminal **104** to the battery cells **101** remains less than a programmed reference current chosen to ensure that a safe charging current is applied to the battery cells **101**. Under certain conditions however, the current flowing from the positive battery terminal **104** to the battery cells **101** may exceed the programmed reference current and charging of the battery cells **101** is provided by the internal battery cell charger **150**.

[34] The battery cell charger **150** is electrically coupled **151** to the positive battery terminal **104** to provide controlled charge of the battery cells **110**. The battery cell charger **150** has a charging output source **150a** that is coupled to the battery cell **101** stack and that may source a safe charging current to the battery cells **101** as controlled by the microcontroller **110** programming. The charger **150** is coupled to the microcontroller **110** (i.e. at "EN-CHRG") and enabled or disabled ("CHRG_DONE") by the microcontroller **110** based on whether the battery cells **101** require charging or have finished charging. In one example the microcontroller **110** directs the charger **150** to charge the battery cells **110** if charging current through the contactor **140** exceeds a safe level of charging current, or the voltage at the positive battery terminal **104** is greater than the accumulated battery cell voltage **102**, or if the accumulated battery cell voltage **102** is below a reference voltage established by programming in the microcontroller **110**.

[35] A low power current path **180** (coupled electrically in parallel to the contactor **140**) from the accumulated battery module voltage **102** to the positive battery terminal **104** allows power from the battery module **100** to power external components such as vehicle engine computers and the like. An exemplary low current path **180** comprises a diode ("D1") and resistor ("R1") coupled electrically in series from the accumulated battery module voltage **102** to the positive battery terminal **104** i.e. with the diode anode coupled to the accumulated battery

module voltage **102**, the diode cathode coupled to a first end of the resistor, and the other end of the resistor coupled to the positive battery terminal **104**.

[36] A voltage source multiplexer Vin Arbiter **120** powers a voltage regulator **125** that supplies internal power to the microcontroller **110**. The Vin Arbiter **120** multiplexes power from the positive battery terminal **104** and accumulated battery module voltage **102** depending upon which voltage potential is greater. Thus, for example when the engine is in the ENGINE_ON state the Vin Arbiter **120** may select and power the voltage regulator **125** from the greater voltage potential of either the positive battery terminal **104** or from accumulated battery module voltage **102**. And when the engine is in the ENGINE_OFF state the Vin Arbiter **120** selects and powers the voltage regulator **125** from the accumulated battery module voltage **102**.

[37] A communications link to and from the battery is provided via a wired or wireless link and facilitates communications with other battery communication links in other battery modules **100** or with other external or remote devices. For example, the microcontroller **110** can be programmed to communicate battery module **100** status information to engine computers or other external devices. Battery module **100** status information may include but is not limited to minimum battery cell voltage, current consumption, error messages, or occurrences of over-current or over-voltage conditions. The communications link is also useful to establish and maintain communications between battery modules **101** that are deployed in parallel or series to augment power requirements or accomplish battery module power **100** redundancies. As illustrated the communications link can be a wired **175** (e.g. I2C® bus) or a wireless **170** (e.g. Bluetooth®) technology.

[38] **FIG. 2** for example illustrates an aggregated battery module **200** having a positive battery terminal **201** and a negative battery terminal **202** but is actually comprised of a plurality of self-contained and independently-internally managed battery modules **100** connected to achieve power objectives beyond that of a single battery module **100**. In particular the aggregated battery module **200** comprises three subsets of battery modules **100** (i.e. the vertical stack of the three rows of battery modules **100** to accumulate “V+”), wherein each of subsets of battery modules **100** (e.g. have been coupled electrically in parallel to sum the battery module **100** current capabilities (i.e. the horizontal rows of four battery modules **100** to accumulate “I+”); and wherein the each of the three subsets of battery modules **100** are coupled in series to sum the voltage capabilities.

[39] The problems normally associated with connecting batteries are addressed by monitoring and managing each of the battery modules **100** connected in parallel using the communications link. As an example, bottom row of battery modules **100** in **FIG. 2** includes a

master battery module **100a** that monitors and manages operations battery modules **100b**, **100c**, **100d** ... that are electrically connected in parallel with the master battery module **100a**. In operation, the master battery module **100a** polls each of the other battery modules **100b**, **100c**, and **100d** ... for information regarding the status of each of the other battery modules **100b**, **100c**, **100d** and in particular the voltage of each individual battery cell in each of the other battery modules **100b**, **100c**, and **100d** ... and issues commands via the communications link to each of the microcontrollers **110b**, **110c**, **110d** ..., to balance each of the individual battery cell voltages to the lowest battery cell **101** voltage or alternatively, a common battery cell reference voltage as established by the master battery module **100a**.

[40] The communications links also enables battery management strategies that promote prolonged battery module **100** life or that facilitate redundant power. The master battery module **100a** may run a program that controls the operation of battery modules **100b**, **100c**, and **100d**, One preferred management strategy is to disconnect each battery module **100** for a time interval and allow the other batteries to supply aggregate power. Thus, in the example if there are N batteries in the aggregate battery module **200** the master battery module **100a** will command one of the other battery modules **100b**, **100c**, and **100d**, ... to open its contactor **140b**, **140c**, or **140d**, ... respectively so that N-1 battery modules **100** are supplying power from the aggregate battery module **200** at any given time. Alternatively, the master battery module **100a** may command more than one of the other battery modules **100b**, **100c**, and **100d**, ... to open its contactor **140b**, **140c**, or **140d**, ... respectively so that fewer than N-1 battery modules **100b**, **100c**, and **100d**, ... are supplying power from the aggregate battery module **200** at any given time.

[41] Finally, the battery module **100** includes a visual status indicator such as a multi-color LED **190** that is coupled to a port on the microcontroller **110** that indicates one or more statuses by the intermittent or steady display of several colors lit by the multi-color LED **190**. Moreover, an accelerometer can be included to ensure that one or more battery module **100** operations are not initiated if the battery module **100** is not in an upright orientation.

[42] While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

AMENDED CLAIMS

received by the International Bureau on 01 December 2015 (01.12.2015)

1. A multi-cell battery control circuit within a battery housing, comprising :
a negative battery terminal and a positive battery terminal that each penetrate and conduct electrical current through the battery housing;

a plurality of battery cells coupled electrically in series and having a combined battery potential proportional to the combined sum of the battery cells,

a microcontroller;

a battery cell voltage balancer having a discharging circuit and a plurality of differential conductive connections, each of the differential conductive connections respectively coupled to positive and negative terminals of one of the battery cells, the cell voltage balancer also having at least one cell balancing output and at least one cell balancing input to transmit and receive cell voltage balancing information to and from the microcontroller, respectively;

a charger having a charger power input, a charger power output, and a charger control input, the charger input coupled to the positive battery terminal, the charger power output coupled to the combined battery potential, and the charger control input coupled to the microcontroller;

a contactor series-coupled between the combined battery potential and the positive battery terminal and having a closed state that permits current to flow between the combined battery potential and the positive battery terminal, and an open state that prohibits current flow between the combined battery potential and the positive battery terminal, the contactor having a contactor control input coupled to the microcontroller; and

a communications link connected to the microcontroller that communicates to a transceiver outside of the battery housing.
2. The multi-cell battery control circuit in claim 1 wherein,
the battery cell voltage balancer differential conductive connections are each coupled to an active device that is coupled to the at least one cell balancing input that controls the active device to discharge current from the respective battery cell, and an analog-to-digital converter input that samples the voltage in the coupled battery cell, wherein the analog-to-digital converter has an output coupled to the microcontroller and data thereon representative of the

charge of the coupled battery cell.

3. The multi-cell battery control circuit in claim 2 wherein,
the at least one cell balancing output comprises a dedicated cell balancing output for each battery cell that is coupled to the microcontroller and the at least one at least one cell balancing input is coupled to the microcontroller.
4. The multi-cell battery control circuit in claim 3 wherein,
the at least one cell balancing output comprises a plurality of cell balancing outputs, one for each battery cell that are coupled between the cell balancer and the microcontroller, and the at least one at least one cell balancing input comprises a plurality of cell balancing inputs, one for each battery cell that are coupled between the cell balancer and the microcontroller.
5. The multi-cell battery control circuit in claim 1 further comprising,
a thermistor and heater coupled to the microcontroller and positioned in thermal communication with the plurality of battery cells to both measure and affect the temperature of the battery cells based on input from the microcontroller.
6. The multi-cell battery control circuit in claim 1 further comprising,
a contactor electrically coupled in series between the combined battery potential and the positive battery terminal, the contactor having a closed state that permits current to flow from the combined battery potential and the positive battery terminal, and an open state that prohibits current to flow from the combined battery potential and the positive battery terminal.
7. The multi-cell battery control circuit in claim 1 wherein,
the contactor is coupled to a bi-directional current sensing circuit, the bi-directional current sensing circuit having a current sense element coupled electrically in series between the combined battery potential and the positive battery terminal, the bi-directional current sensing circuit having an output coupled to the microcontroller.
8. The multi-cell battery control circuit in claim 7 wherein,
the bi-directional current sensing circuit includes a current-to-voltage converter that produces an output that is representative of the polarity of the current flowing through the current sense element, the output coupled to the microcontroller.

9. The multi-cell battery control circuit in claim 8 wherein,
the bi-directional current sensing circuit further includes an amplifier with an input coupled to the microcontroller and the input conducts a signal that modifies the gain of the amplifier.
10. The multi-cell battery control circuit in claim 1 further comprising,
a low-power path coupled electrically parallel to the contactor.
11. A method of managing a battery module, the battery module having a positive battery terminal and a negative battery terminal, a plurality of battery cells with an accumulated battery cell voltage, the battery module further includes a contactor coupled electrically in series between the accumulated battery cell voltage and the positive battery terminal, a charger that is coupled to the positive battery terminal and has a charger output coupled to the accumulated battery cell voltage, the method comprising:
opening the contactor to create an open circuit between the accumulated battery cell voltage and the positive battery terminal to manage the battery module use or non-use.
12. The method in claim 11, further comprising:
charging the plurality of battery cells by current flowing from the positive battery terminal through the contactor if the current flowing from the positive battery terminal through the contactor is less than a reference current;
opening the contactor if the current flowing from the positive battery terminal through the contactor is greater than the reference current; and
charging the plurality of battery cells from the charger if the current flowing from the positive battery terminal through the contactor is greater than the reference current.
13. The method in claim 12, wherein the battery module further includes a heater and thermistor, the method further comprising:
reading the temperature of the plurality of battery cells using the thermistor prior to charging the plurality of battery cells;
comparing the temperature of the plurality of battery cells to a reference temperature;
and
charging the plurality of battery cells if the temperature of the plurality of battery cells

exceeds the reference temperature, else;

heating the plurality of battery cells if the temperature of the plurality of battery cells is less than the reference temperature.

14. The method in claim **12** wherein the battery module includes a communication link coupled to a receiver external to the battery module, the method further comprising:

sensing an original accumulated battery cell voltage;

detecting each occurrence wherein the accumulated battery cell voltage decreases at least twenty percent below the original accumulated battery cell voltage; and

transmitting via the communication link an indication of each occurrence wherein the accumulated battery cell voltage decreased at least twenty percent below the original accumulated battery cell voltage to the receiver.

15. The method in claim **14** further comprising:

detecting each subsequent occurrence wherein the accumulated battery cell voltage increases above the original accumulated battery cell voltage;

detecting each subsequent occurrence wherein the accumulated battery cell voltage decreases to a voltage that is within five percent of the original accumulated battery cell voltage; and

transmitting via the communication link an indication of each occurrence wherein the accumulated battery cell voltage decreases to a voltage that is within five percent of the original accumulated battery cell voltage to the receiver.

16. The method in claim **11**, wherein the battery module is a master battery module of a plurality of battery modules, wherein the plurality of battery modules have the positive battery terminals coupled together and the negative battery terminals coupled together, respectively, the method further comprising:

sampling the voltages on the plurality of battery cells in each of the other plurality of battery modules;

communicating the voltages sampled in each of the other plurality of battery modules to the master battery module;

comparing the sampled voltages in the plurality of battery modules to determine a battery module and a battery cell within having a lowest sampled voltage; and

discharging the battery cells in all of the battery modules that have battery cell voltages greater than the lowest sampled voltage until the battery cells in the plurality of battery cells have substantially the same voltage as the lowest sampled battery cell voltage.

17. The method in claim **16** wherein the plurality of battery modules is N battery modules, , the method further comprising:

opening at least one of the contactors at a time so that N-1 or fewer contactors are closed; and

sourcing current from the N-1 or fewer battery modules.

18. An aggregate battery, comprising:

a plurality of battery modules each battery module including

a positive battery terminal and a negative battery terminal,

a plurality of battery cells electrically coupled in series to create an accumulated battery cell voltage,

a contactor coupled between the positive battery terminal and the accumulated battery cell voltage, the contactor with an open state that prohibits current flow and a closed state that permits current flow,

a charger coupled between the positive battery terminal and the accumulated battery cell voltage, and

a battery cell balancer coupled to the plurality of battery cells,

a microcontroller coupled to and having a process to control each of the contactor, the charger, and the battery cell balancer, and

a communications link coupled to the microcontroller for communicating with at least one of the other plurality of battery modules;

wherein a first subset of the plurality of battery modules have the positive battery terminals coupled together and the negative battery terminals coupled together, respectively, the

communications link of each of the first subset wirelessly coupled to the communication link in at least one of the other battery modules in the first subset.

19. The aggregate battery in claim **18** further comprising:

a second subset of the plurality of battery modules have the positive battery terminals coupled together and the negative battery cells coupled together, respectively, the communications link of each of the second subset wirelessly coupled with the communication link in at least one of the other battery modules, and the negative terminals of the second subset coupled to the positive battery terminals of the first subset.

20. The aggregate battery in claim **19** wherein,

each of the second subset of the plurality of battery modules are wirelessly coupled with the communication link in one of the battery modules in the first subset.

21. The method in claim **11** wherein,

opening is upon detection of an occurrence of a fault condition selected from over-current flowing through the contactor, or over-voltage at the plurality of battery cells, the positive battery terminal, or the contactor.

22. The method in claim **21** wherein the battery module further includes a bi-directional current sensing circuit with a current-sense element coupled to the positive battery terminal, and the bi-directional current sensing circuit also having an output coupled to the microcontroller, the method further comprising,

sensing at the current-sense element to detect the occurrence of a fault condition.

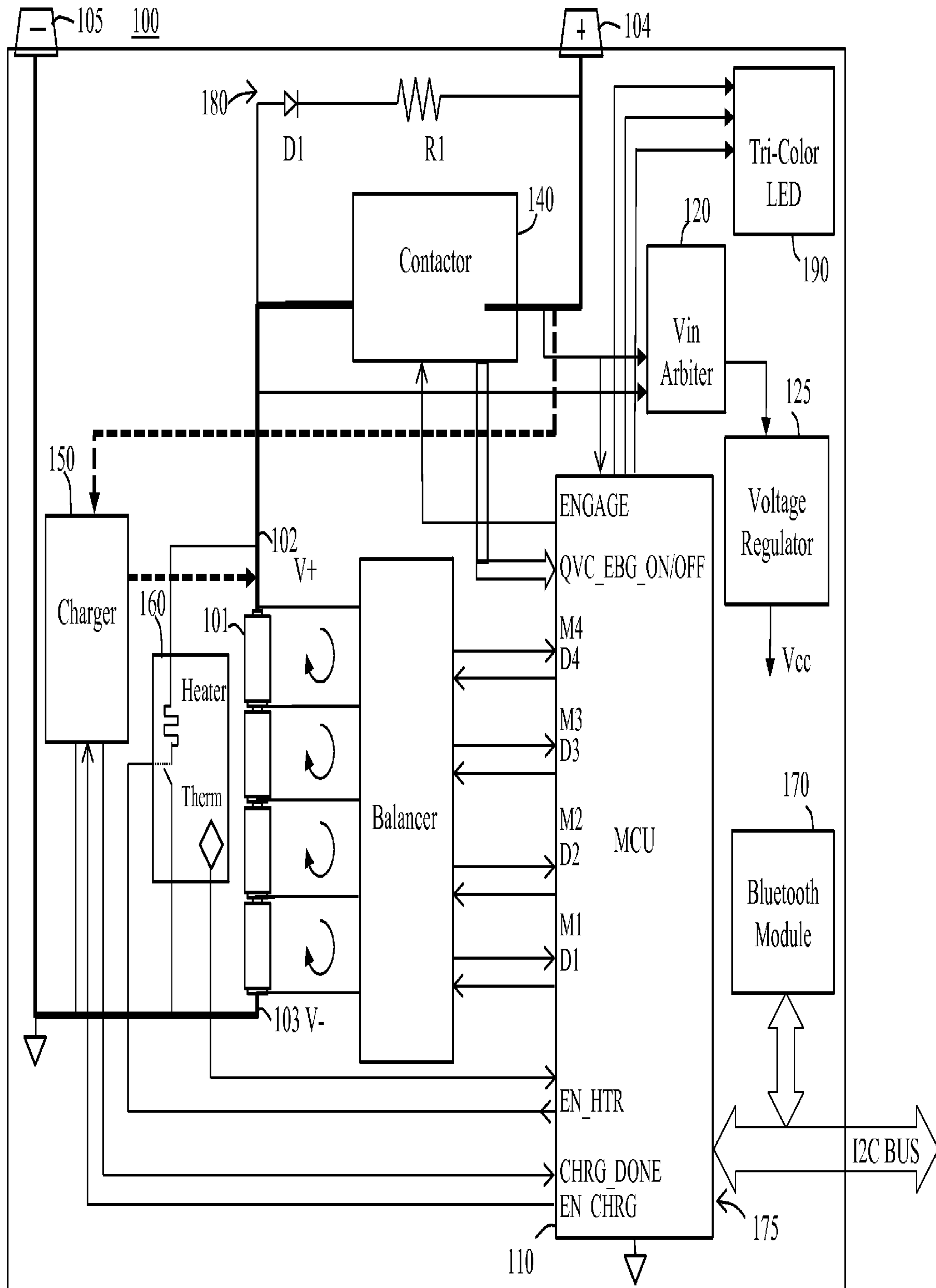


FIG. 1

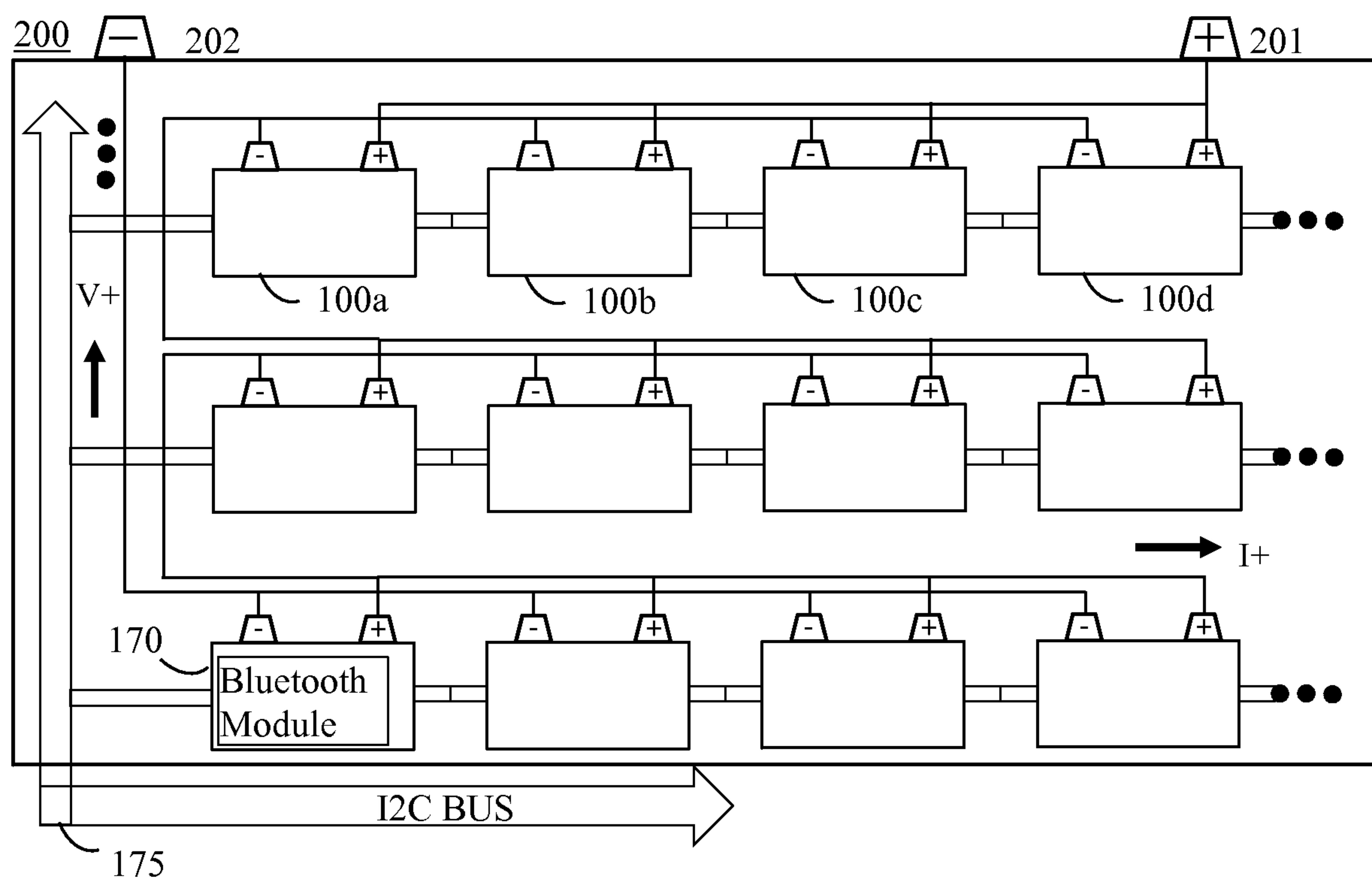


FIG. 2

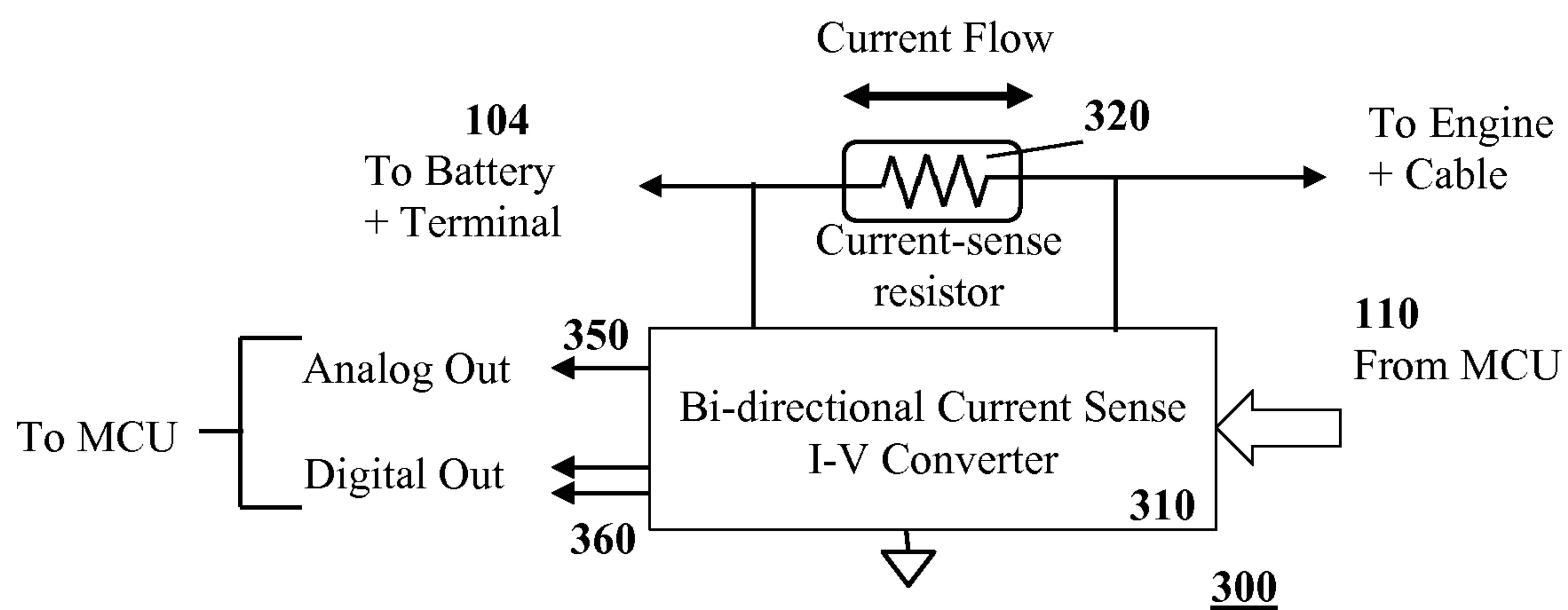


FIG. 3

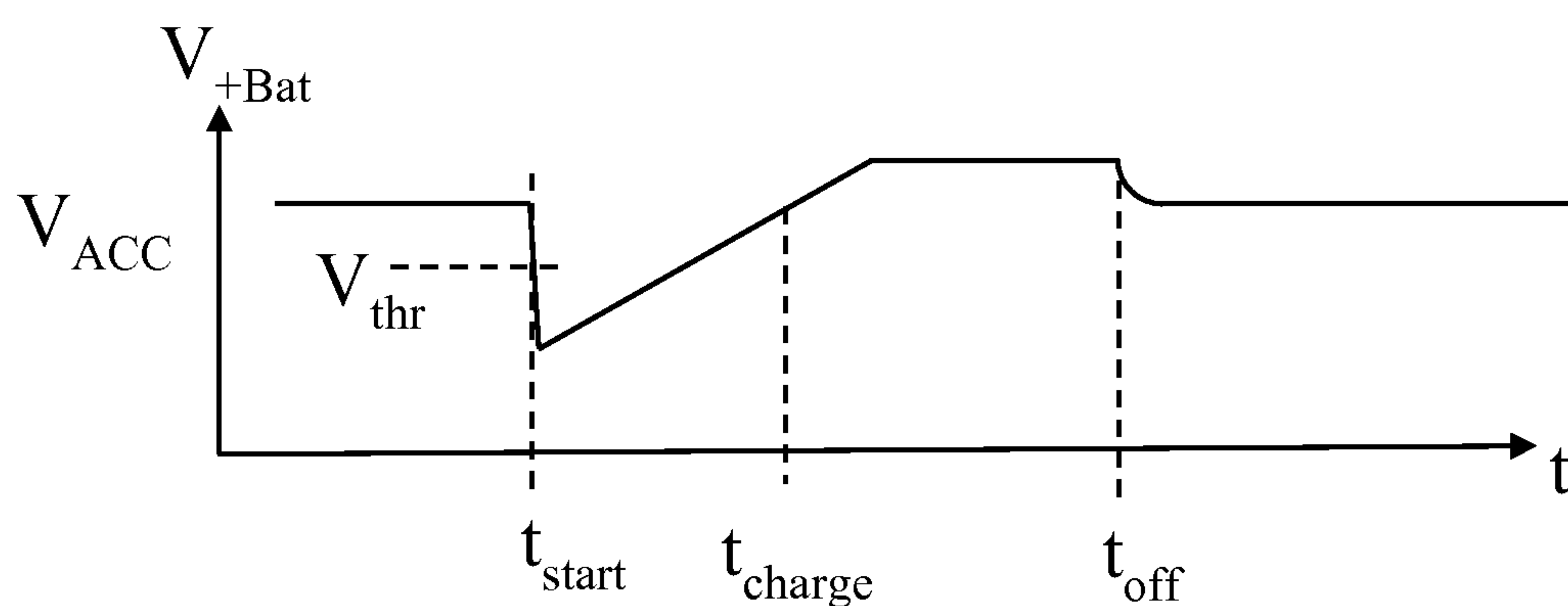


FIG. 4

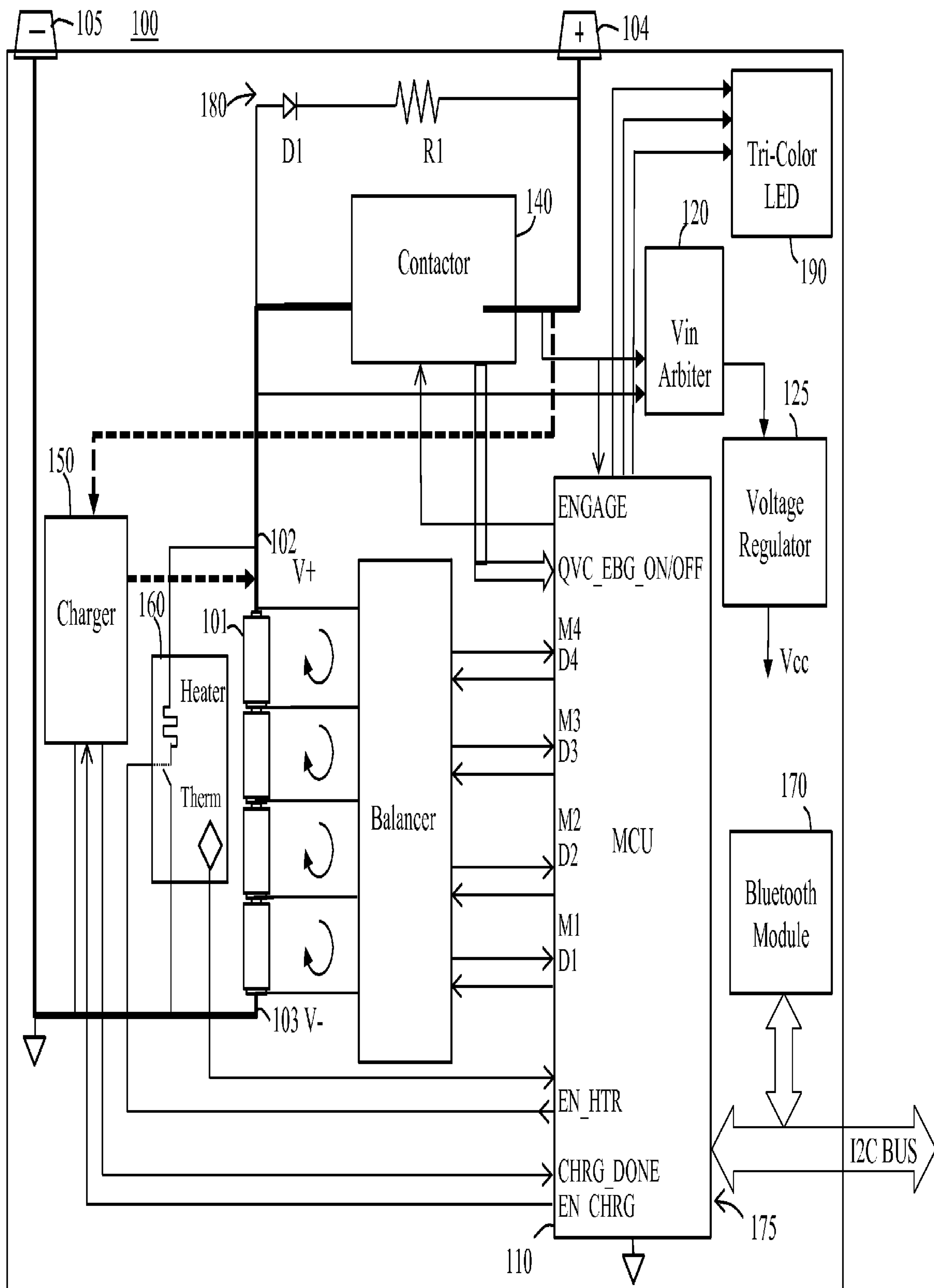


FIG. 1