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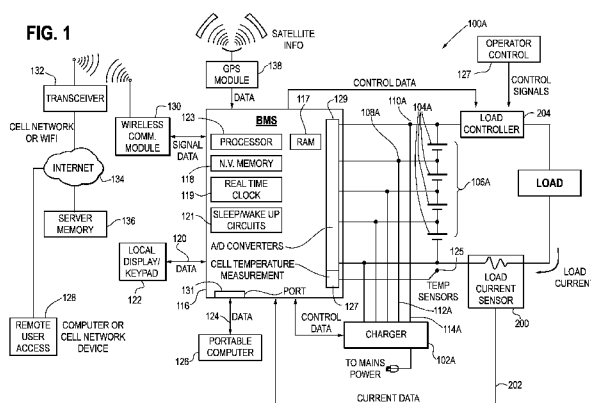
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(54) Title: METHOD AND APPARATUS FOR MANAGING MULTI-CELL BATTERIES



(57) Abstract: A method and apparatus for the intelligent management of multi-cell battery pack. A battery management system which may be mounted on board a vehicle facilitates battery management including monitoring the state of charge of the battery pack. Wireless communication equipment facilitate communication between the battery management system to a remote location. A battery charger controlled by the battery management system charges individual cells of the battery pack. A battery charging system and method, includes a high voltage charger for charging a group or string of series connected battery cells, and a group of individual cell chargers for charging individual ones of the cells. The charging technique includes detecting at least one cell being charged to a predetermined voltage, and then inhibiting the high voltage charger from further charging any of the cells. The individual cell chargers charge individual ones of the cells, except the at least one cell charged to the predetermined voltage. An individual cell charger and method of using it are disclosed. The voltage of each individual battery cell of a series connected cell configuration, is measured. A controlled power source charges the cells individually at an initial voltage. The voltage on each individual one of the charged cells is subsequently measured by a battery management system. The voltage of the controlled power source is incrementally increased to charge the cells individually at an incrementally higher voltage. The measuring and charging of each individual cell is repeated until the voltage on at least one of the cells reaches

a predetermined voltage. Once the voltage on at least one of the cells reaches a predetermined voltage, the measuring and charging each individual cell continues at substantially the same last incremental voltage.



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METHOD AND APPARATUS FOR MANAGING MULTI-CELL BATTERIES

Related Patent Applications

5 This present non-provisional patent application hereby claims priority to U.S. provisional patent application No. 61/323,835, filed April 13, 2010, for INTELLIGENT BATTERY MANAGEMENT SYSTEM AND METHOD, which is incorporated herein by reference.

10 This present non-provisional patent application hereby claims priority to U.S. provisional patent application No. 61/319,187, filed March 30, 2010, for BATTERY CHARGING SYSTEM AND METHOD, which is incorporated herein by reference.

15 This present non-provisional patent application hereby incorporates by reference U.S. patent application No. 13/075,137, filed March 29, 2011, entitled BATTERY CHARGING SYSTEM AND METHOD; U.S. patent application No. 13/075,152, filed March 29, 2011, entitled INDIVIDUAL CELL CHARGER AND METHOD OF USING SAME; and U.S. patent application No. 12/650,401 filed December 30, 2009, entitled SYSTEMS AND METHODS FOR MANAGING CHARGE AND DISCHARGE FOR BATTERIES.

Field of the Invention

20 The present invention relates in general to a system and method for managing the charging and discharging functions of multiple-cell batteries. It more particularly relates to an intelligent system and method for managing the charging and discharging functions of multiple-cell batteries, while collecting and analyzing cell performance data to optimize or at least improve battery operation and to permit the monitoring of such cell performance data within fleets or groups of battery-powered vehicles, mobile
25 equipment, and others.

The present invention also relates in general to a battery charging system and method, and it more particularly relates to such a system and method for managing the charging of multiple cell batteries efficiently and effectively.

The present invention relates in general to an individual cell charger and a method of using it. It more particularly relates to an individual cell charger and method for charging multi-cell series connected batteries.

Background of the Invention

5 This section includes descriptions of background art in the field of disclosed embodiments of the present invention. There is no intention, either express or implied, that any background art discussed in this section legally constitutes prior art.

 There have been a variety of battery management systems. For example, reference may be made to U.S. patent 6,005,367, which is incorporated herein by
10 reference.

 Recent improvements in storage batteries, especially in Lithium Ion (Li Ion) technology, have given rise to more widespread use of batteries to power mobile equipment and vehicles that have been traditionally powered by internal combustion engines. While battery power is often preferred due to environmental considerations, it
15 also provides other advantages such as reliability, safety and quiet operation.

 Li Ion cells typically display terminal voltages in the range of 3 to 4 volts, which is not high enough to power typical drive motors. This limitation can be overcome by connecting Li Ion cells in series, so their voltages add up until an appropriate pack voltage is achieved to power the particular application.

20 To achieve a desired battery lifetime, battery manufacturers specify the operating parameters for cells in terms of the maximum voltage during charge, and the minimum voltage during discharge. Batteries must be charged and discharged within these parameters, to deliver an expected number of charge / discharge cycles during their lifetime. In order to control and manage battery charging and discharging within the
25 specified parameters, most applications require use of a Battery Management System (BMS). The BMS typically monitors the individual cells and is able to control both the charge and discharge functions to insure that the cells are charged and discharged in accordance with their specifications.

The cells need to be balanced in both energy capacity and charge in order to deliver their optimum performance. For example, if an individual cell within in a battery pack of cells connected in series is under-charged relative to other cells within the pack, the under-charged cell will discharge to its minimum voltage before the other cells. In this case the BMS will shut down the discharge process, even though useable charge remains in the other cells.

The same is true if an individual cell has a lower capacity than the other cells in a pack: even though all cells are fully charged at the start, the low capacity cell may discharge first and the BMS will shut down the discharge process, even though the other cells may contain useable charge. Recent improvements in BMS/charger technology such as, for example, the BMS technology described in U.S. Patent Applications 12/650,401, filed December 30, 2009 and 61/319,187, filed March 30, 2010, are each incorporated herein by reference, and have enabled a BMS to provide that all cells are fully charged prior to use. However, capacity matching remains an important consideration.

Since cell capacity is subject to degradation over time and usage, it is important to monitor cell performance to assure proper operation is being achieved, even if cells are initially matched. Monitoring cell performance involves the collection and analysis of large amounts of data, and can be quite laborious if done manually. This is especially true when the number of battery-powered vehicles or pieces of equipment is large, such as, for example, a fleet of golf carts, or warehouse material handling trucks. Particularly in such cases, it would be useful to facilitate the data collection and analysis by providing a BMS with "intelligence." Therefore, due to the nature of batteries made up of multiple Li Ion cells, and the advantages of powering large numbers of vehicles or equipment powered by such batteries, a need exists for a system that can provide this functionality in a more efficient and effective manner.

There are many different kinds and types of battery powered devices and apparatus. For example, battery powered vehicles are coming into increasing use. New battery technologies such as Lithium Ion are playing an increasing role in that application. One of the most important considerations for them is their range. While

Lithium Ion cells provide substantial advantages over the old lead acid technology, such as larger capacity to weight and capacity to volume ratios, they have also presented certain challenges to realizing their full potential. In an application such as electrically powered vehicles, it is necessary to connect cells in series in order to achieve practical voltage levels to be compatible with available controllers and motors.

Doing so presents an issue relating to battery cell balance. If one cell in a series string charges significantly differently from the others, it can cause performance to be degraded. For example, many cell strings or battery packs use a Battery Management System (BMS) to monitor battery conditions. Since cells are normally charged in series by one charger, a single cell in a string having a voltage that is too high during the charge cycle may trigger the BMS to shut down the charger. If that high cell had a voltage much higher than the others in the battery packs, the others could have had their charge cycle terminated prematurely in order to protect the high cell. Thus, the other cells may not be fully charged, thereby resulting in the vehicle range being undesirably reduced.

Conversely, during discharge, a cell that has a voltage much lower than the others could trigger the BMS to initiate vehicle shut down, even though the other cells may have had reserve capacity, once again reducing the range undesirably. It can be seen that both unbalanced high, and unbalanced low cells may cause the previously described range problems.

A charge imbalance can occur from several sources. For example, different cells in series may store energy at different rates even though they all share the same charge current. Also, some cells in use may have more discharge current than others if, for example, they comprise a portion of the cells that are sometimes used to power a low voltage load such as lights. Thus, it may be desirable for some applications to provide substantial charge balance in a series string of cells, to improve the amount of useable energy stored in them. In a vehicle application, this may provide the delivery of an improved range for given applications.

In the past, several approaches have been taken in an attempt to accomplish balance in a series string of cells. A common approach has been to compare voltages

of the different cells during charge, and shunt some current around the higher voltage cells to reduce their charge current while leaving the full current flowing through the lower voltage cells. This approach may work for some chemistry batteries, but not well for Li-Ion chemistry cells. One reason is that for some applications, it may well be difficult or impossible to determine the amount of the state of charge on individual cells during the charging process.

This limitation can be seen by referring to FIG. 2. Here, the voltage is shown as a function of energy flowing into a partially discharged Li-Ion cell. It can be seen that the voltage is almost constant during most of the charging process, and only changes near the end of charge. It is therefore difficult to determine the state of charge by looking at the cell voltage until it is almost completely charged. Because of this, cells with differing states of charge may not be accurately differentiated from one another during most of the charge process, and therefore appropriate current shunting may not readily be accomplished at least for some applications. When voltage differences do become evident, the charge is nearly complete for the highest cells, and it may be too late to accomplish a balance by making a modest reduction in the current through them, since the conventional BMS may turn off all charging when the first cell may be fully charged and its voltage may reach the maximum allowable. At that point, the lower voltage cells may not be fully charged, and thus, the imbalance may remain.

There is also a need for an individual cell battery charger which is primarily to insure that all cells become fully charged and balanced in a fast expeditious manner. In this regard, battery cell balance is an issue during charging operations for multi-cell series connected batteries. This may be particularly true for Lithium ion cells. If one cell in a series string charges significantly differently from the others, it can cause performance to be degraded.

A conventional method of individual cell charging is to provide a charger for each cell comprised of an individual switcher with its associated transformer (or transformer winding), rectifiers, filters and control circuitry. For charging a multi cell battery pack this approach may be expensive to manufacture, may be bulky and may have limited reliability because it involves many parts.

Brief Description of the Drawings

In order to better understand the invention and to see how the same may be carried out in practice, non-limiting preferred embodiments of the invention will now be described with reference to the accompanying drawings, in which:

5 The features of this invention and the manner of attaining them will become apparent, and the invention itself will be best understood by reference to the following description of certain non-limiting preferred embodiments of the invention taken in conjunction with the accompanying drawings, wherein:

10 FIG 1. is a schematic diagram of an intelligent battery charging system, which is constructed in accordance with an embodiment of the present invention;

 FIG. 2 is a graph illustrating a Lithium Ion battery cell voltage verses the energy supplied to the cell;

 FIG. 3 is a simplified block diagram of a prior known battery charger;

15 FIGS. 4A and 4B comprise a flow chart diagram of a method of operating the system of FIG. 3; and

 FIG. 6 is a schematic circuit diagram of an individual cell charger, which is constructed according to an embodiment of the present invention.

Certain Embodiments of the Invention

20 It will be readily understood that the components of the embodiments, as generally described and illustrated in the drawings herein, could be arranged and designed in a wide variety of different configurations. Thus, the following more detailed description of the embodiments of the system, components and method of the present invention, as represented in the drawings, is not intended to limit the scope of the invention, as claimed, but is merely representative of embodiments of the invention.

25 In accordance with at least one embodiment of the present invention, there are provided a system and method for the automated collection and analysis of performance data of individual battery cells, connected in series, within battery packs.

Such automated data collection and analysis functions, as well as other functions described below, may be particularly useful in the management of fleets of electric vehicles or other mobile equipment. In this regard, each vehicle or mobile equipment would have a battery management system on board and be able to communicate
5 wirelessly to a central stationary remote user access. A portable computer and/or a local display/keypad enables the vehicle operator to obtain data as well.

In an embodiment of the present invention, the BMS may perform normal battery management functions such as controlling a battery charger either locally or remotely to prevent individual cells from exceeding a maximum voltage specification during
10 charging. In another aspect of an embodiment of the present invention, the BMS may operate a load controller to prevent individual cells from being drained to a voltage lower than a minimum voltage specification, or from exceeding a maximum temperature specification. The BMS may perform such functions by sampling individual cell voltages and temperatures at predetermined intervals. For example, in an aspect of the
15 invention, the BMS can sample individual cell parameters such as cell voltage and temperature at least 100 times per second. By averaging at least 10 such readings, and comparing this average with the cell specifications, the BMS may generate a signal to limit charging or loading. If BMS sampling of cell parameters indicates that any cell parameter deviates from respective cell specifications, the BMS may record such event
20 data in a memory storage medium with a time stamp.

In another embodiment of the invention, the BMS may include a wireless, satellite-based, or local communication medium that is known in the art, to facilitate the collection of battery cell data from battery-powered mobile equipment or vehicles and uploading of such data to a central or remote data storage facility. A BMS configured
25 with such a wireless, satellite-based, or local communication medium can also facilitate the transmission of instructions to the equipment or vehicle. The communication medium may take the form of cell phone data transmission, WiFi connectivity, communication via satellite link, or other, depending on particular needs. For example, it may be particularly advantageous to communicate with equipment that is housed,
30 stored, or otherwise grouped together in a central charging area, using WiFi technology, since the communication distances are relatively short between a WiFi hotspot and a

vehicle or piece of mobile equipment being charged in such a central area. Alternatively, cellular network technology may more advantageously facilitate communication with electric delivery trucks in an urban area that are charged singly at geographically dispersed charging stations.

5 The state of charge of Li Ion cells may be determined by measuring their internal impedance and temperature. The BMS is capable of gathering and compiling this data in real time (as individual cells are being drained in use), by measuring the load current and cell voltage concurrently with temperature, and comparing successive measurements at different current draws, at close enough intervals that the temperature
10 is not substantially different. The cell resistance may then be calculated by the equation $R=(V_2-V_1)/(I_2-I_1)$. The BMS may determine the state of charge of a particular cell by averaging a number of readings and finding the charge value in a look-up table entry for the corresponding temperature. Such a table may be predetermined by characterization tests of the type of cells in use. During this process the data sample
15 rates may also be increased to capture the transients that occur during loading. For example, the sample rates may be set to at least one reading per millisecond to do so. Calculation results may be averaged and displayed to the operator with 10 second updates and may be stored locally, with a periodic time stamp, for example, every minute during discharge. The data storage medium may be integrated with the
20 powered device. For example, it may be located onboard the vehicle or other mobile equipment. Thus, the state of charge calculation may be used by the BMS to estimate the remaining usable energy in the pack, and the information can be presented to the operator. It is noted that for this calculation the weakest cell information is the determining factor.

25 As discussed above, in an embodiment of the invention, the BMS may incorporate data collection, storage and retrieval capability. Charging data, cell voltage, temperature, state of charge and certain other data may be stored locally with time/date stamps. Such locally-stored data may be compiled and periodically sent through a wireless, satellite-based, or local communications medium to a remote data server, by
30 the BMS, where the data can be accessed at any time. The remote data server may be connected to the Internet, and configured for communication via the Internet. In an

embodiment of the invention, the data may also be accessible by wireless or satellite link, or locally by an operator or service technician. In another embodiment of the invention, the BMS may allow data to be collected "on demand" through the same communication means. This may allow fleet managers or others to access data
5 revealing charging, usage and maintenance patterns, and the current health of the battery systems in a fleet of vehicles or other mobile equipment.

In managing such a fleet of battery-powered vehicles, gathering and providing access to GPS information can be advantageous. In various scenarios, it may be important for a manager to know individual fleet vehicles or equipment are located. For
10 example, if a battery or other problem arises in the field, it may be important to know the location of the equipment or vehicle so it can be serviced or retrieved. Also, it may be important for the manager to know if a vehicle or equipment has been taken outside of a pre-determined area boundary. Accordingly, in another embodiment of the invention, the BMS is capable of acquiring GPS data, and sending an immediate message, via
15 wireless, satellite-based, or local communications medium, noting such events at the time that they happen, as well as noting and storing routine location information periodically for later retrieval and analysis. In an embodiment of the invention providing for two-way wireless or satellite-based communication with a vehicle or piece of equipment, a manager may also send a location query at any time and receive an
20 immediate response.

Remote control functionality incorporated into another embodiment of the invention is another feature that is advantageous in managing a fleet. Particularly in an electric vehicle application, the need may arise to immobilize the vehicle, or terminate travel by remote means, for example, in a security breach situation, or if it becomes
25 known to a manager that equipment is being used in an improper way. In these cases it may be necessary for an authorized person or manager to over ride the commands of an operator. Integrating wireless, satellite-based, or local communications capability into the BMS is a mode of enabling this remote control functionality whereby the BMS can carry out the steps to disable or immobilize a vehicle or piece of equipment.

Another embodiment of the present invention may include functionality to provide maintenance reminders for a device powered by batteries managed by the BMS. Such reminders may take the form of an onboard message to the operator, a message transmitted to a manager, or an entry in a data log on a server connected to the internet. The BMS may generate such maintenance reminders based on a predetermined maintenance plan, and a comparison with stored usage data. The communication of maintenance information to and from the powered device may occur via wireless, satellite, or local communication modes.

It is advantageous for battery charging to occur during economical windows of time. It is generally known that an electrical power supply grid has periods of low usage and that power companies often encourage “off peak” consumption by offering reduced rates during such periods. In another embodiment of the invention, the BMS may be configured with a real time clock, and the BMS may be programmed to control the charger in a way that charging only occurs during “off peak” periods, to obtain the greatest economy.

It may also be advantageous to require authorization to operate a device powered by batteries controlled by a BMS according to the present invention. In another embodiment of the invention, the BMS may have the capability to require an operator to enter an authorization code before the powered equipment can be operated. The code may be set and changed either locally or remotely by an individual using a system management code. Such operation and transmittal of data may occur via wireless, satellite, or local communication modes that are known in the art.

Another embodiment of the present invention may include a BMS with the capability to receive firmware upgrades through wireless, satellite, or local communication mediums.

It is advantageous to limit BMS power consumption, to avoid draining the battery when the vehicle or equipment is not in use, and the BMS is not active. In another embodiment of the invention, the BMS may be configured to enter a “sleep” mode which consumes very low power. A BMS according to an embodiment of the present

invention may also have a low power “wake-up” sensor that “wakes-up” the BMS (*i.e.*, returns the BMS to a “non-sleep” mode) when certain events take place:

Referring to FIG. 1, there is shown a schematic view of an “intelligent” BMS system 100A according to an embodiment of the present invention, with elements
5 capable of performing functions described above. The system 100A illustrated in FIG. 1 provides a battery cell charger 102A, connected to individual battery cells 104A connected in series, in a string forming a battery pack, shown generally at 106A. In order to charge each cell 104A, the charger 102A is connected to cell terminals of each cell 104A, such as terminals 108A and 110A, through a pair of connections, such as
10 connections 112A and 114A. Also shown is a BMS 116 that, among other functions, has analog to digital converters 129 that monitor the state of charge of the battery pack 106A, and the individual cells 104A. The system 100A may be configured for use with various types of battery powered devices, such as mounted onboard vehicles and mobile equipment, among others. The device (not shown) powered by the battery pack,
15 106A, whether a vehicle, or item of mobile equipment, or other battery-powered device, is represented by a load 204 on the battery pack 106A. It is to be understood that the embodiments of the present invention, whether or not disclosed herein, may or may not relate to charging batteries used in vehicles, as there are a variety of other applications which are also contemplated.

20 In various aspects of the invention, the BMS 116 may be configured to include data storage media such as random-access memory 117, non-volatile memory 118, a real-time clock 119, and sleep/wake-up circuitry 121. In another aspect of the invention, a processor 123 of the BMS 116 may receive inputs from sensors such as sensor 125 and supplies it to a cell temperature measurement unit 127 that measure the
25 temperature, voltage, and current of individual cells 106A. In keeping with the spirit of the embodiments of the invention, such data may be communicated to the BMS 116 through various types of wired or wireless data connections. In one embodiment of the invention, load current sensor 200 transmits current data to the BMS 116 via data connection or lead 202.

In another embodiment of the invention, the BMS 116 provides control data to a load controller 204 in order to prevent individual cells from being drained to a voltage lower than a minimum voltage specification, or from exceeding a maximum temperature specification. In an embodiment of the invention, an operator control 127 for an operator of the device or equipment powered by the battery pack 106A may receive messages from the BMS processor 123 regarding the state of charge, or other parameters of the cells 102A or battery pack 106A. Based on the content of the message, an operator may issue control signals to the load controller 204 to prevent individual cells 104A from being drained to a voltage lower than a minimum voltage specification, to prevent individual cells 104A from exceeding a maximum temperature specification, or for other purposes.

In another embodiment of the invention, the BMS 116 may incorporate a port or other connection 120 to provide for local communication and data transfer between BMS 116 and an input/output device 122 such as a local display keypad. A user or operator such as a person on board a vehicle (not shown) powered at least in part by the battery pack 106A, can thus view and download data collected and stored by the BMS 116. The user or operator can also issue commands or upload other programming, instructions or firmware to the BMS 116. Another embodiment of the invention may include a port or other connection 124, to facilitate this type of two-way communication and data transfer between the BMS 116 and a portable computer 126.

In yet another embodiment of the invention, the BMS 116 may be connected to a wireless communication medium, for two-way communication with a remote user access point 128, where a remote user, operator, administrator or manager may view and download data collected and stored by the BMS 116, and issue commands or upload other programming, instructions or firmware to the BMS 116. To facilitate such communication, the BMS may be connected to a wireless communication module 130, which communicates with a wireless transceiver 132 via a wireless communication protocol which may be known in the art, such as, for example, WiFi, WiMax, Bluetooth, or a satellite communication connection protocol. The transceiver 132 may be connected to the remote use access point 128 via the Internet 134. In an embodiment

of the invention, the Internet can also facilitate data transfer to a storage medium on a remote server 136.

In another embodiment of the invention, a GPS module 138 may be connected to the BMS 116. The GPS module 138 may provide location data to the BMS 116, and may also be configured to wirelessly transmit the location of a vehicle or other piece of mobile equipment in which the BMS 116 may be installed. In certain embodiments of the invention, such wireless transmittal of location data may be facilitated by satellite link, or via a wireless communication module 130, which is attached to the BMS 116, and is described in greater detail, above.

10 Trickle Charge System

In accordance with at least one embodiment of the present invention, there is provided a battery charging system and method, including a high voltage charger for charging a group or string of series connected battery cells, and a group of individual cell chargers for charging individual ones of the cells. The charging technique includes detecting at least one cell being charged to a predetermined voltage, and then inhibiting the high voltage charger from further charging any of the cells. The individual cell chargers charge individual ones of the cells, except the at least one cell charged to the predetermined voltage.

According to certain embodiments of the invention, the individual cell chargers continue to charge the individual cells until each one is charged to the predetermined voltage. As each cell reaches that voltage level, its individual cell charger is inhibited from further charging its cell.

According to the other embodiments of the invention, the individual cell chargers may charge their individual cells at the same time the high voltage charger applies charging current through the series connected cells. Thus, when the high voltage charger becomes inhibited, the individual cell chargers continue to supply charging current to their individual cells.

According to certain embodiments of the invention with reference to the drawings, an apparatus for charging batteries, and the method for doing the same, are

disclosed. Referring now to FIG. 3 of the drawings, there is illustrated a schematic diagram of a known, prior-art apparatus 1, configured for charging a string of individual battery cells generally indicated at 2, forming a battery pack connected in series. A BMS 4 monitors the state of charge of each individual cell such as cell 6. The BMS 4 may be of any appropriate type known in the art, such as, for example, the BMS described in U.S. Patent Application No. 12/650,401, filed December 30, 2009, incorporated herein by reference. A high-voltage charger 8 outputs a voltage appropriate across the entire string of series connected cells 2, and the same charge current flows through each of the cells 6. It can be seen that the BMS 4 has a pair of connections such as connections 10 and 11 each cell such as the cell 6, to each of the cell terminals such as cell terminals 12 and 13 of the cell 6, in order to monitor the voltage of the respective cells such as the cell 6. The BMS 4 monitors the voltage of each cell such as the cell 6 and may be configured to terminate the charge current if the voltage of any cell such as the cell 6 reaches a pre-determined upper voltage limit.

Referring now to FIGS. 4 and 5 of the drawings, there is shown a battery charging system 100 for charging a battery generally indicated at 106 comprised of series connected cells such as a cell 104, in accordance with an embodiment of the present invention. It should be understood that while only four cells are illustrated in FIG. 4, a fewer number or a larger number of cells may be charged by the system 100. FIG. 5 illustrates a flowchart for a method of using the embodiment of the invention shown in FIG. 4, to charge batteries. The system 100 illustrated in FIG. 4 provides individual cell chargers generally indicated at 102 for each individual cell such as the cell 104 of the string of cells connected in series generally indicated at 106. A BMS 108 monitors the state of charge of the battery 106 and individual cells such as the cell 104.

During the charging process, each individual cell charger 102 monitors the voltage of each respective individual cell such as the cell 104, and compares the voltage to a predetermined upper voltage target. If the voltage of a cell such as the cell 104 is below the predetermined upper voltage target, the associated individual cell charger 102 continues to inject charging current into the cell 104, until the predetermined upper voltage target is reached.

This process may occur concurrently with charging current flowing from a high-voltage charger 110 through the series connected cells of the battery 106. Thus a depleted battery 106 may receive current from both the high voltage charger 110, and individual cell chargers 102 at the same time. Alternatively, the individual cell chargers 102 may start charging individual cells only after the high-voltage charger 8 is inhibited.

When the voltage of any cell reaches a predetermined upper limit, the BMS 108 turns off or otherwise inhibits the high-voltage charger 110 from further charging the whole string of cells. Also the individual cell chargers 102 are turned off or otherwise inhibited from further charging its associated cell such as the cell 104 that has reached the predetermined upper voltage limit. However, the individual cell chargers 102 for the remaining cells continue to charge their associated cells until they each also reach the upper limit. Thus the individual cell chargers 102 continue charging their associated cells until the voltage of each of the cells reaches the predetermined upper voltage limit.

Charge balance is thus achieved for all cells 104 in the string of cells of the battery 106. It is advantageous and presently preferred for the two forms of charging to work together harmoniously simultaneously, as described, because each has its own strength. The high voltage charger 110 is typically capable of delivering high charge currents, and thus injects energy into the cells 106 very quickly. The individual cell chargers 102 are capable of providing relatively smaller charge current outputs, in order to improve the efficiency and economy of this embodiment. Since the individual cell chargers 102 are only making up the difference in charge balance between the cells 106, their current delivery rate is adequate to charge their associated cells 106 up to a predetermined upper voltage limit within a reasonable time.

Still referring to FIG. 4, in other embodiments of the invention, the power for the individual cell chargers 102 may be supplied either directly from a power main 112, or from the high voltage charger 110, depending on the application. The BMS 108 ensures that power is never drawn from the cell string 106 when neither the mains, nor the charger 110 is available to power the individual cell chargers 102. The BMS 108 does so using the information provided via the high voltage charger control/feedback

line 114. This is done because the cell string 106 is incapable of raising its own voltage and may otherwise discharge undesirably.

Referring now to FIG. 5 of the drawings, there is illustrated a flowchart 200 describing a method of using the apparatus of the present invention to charge batteries, in accordance with an embodiment of the invention. FIG. 4 is also referred to, in connection with the description of FIG. 5, to illustrate how components of the apparatus may function to carry out the steps of the method. When charging is initiated at box 202 of FIG. 5A, and during the charging process, the BMS 108 monitors the state of charge of the battery and individual cells, and controls the operation of the high-voltage charger 110 and the individual low-voltage cell chargers 102, as shown by box 204 of the flowchart. In an embodiment of the invention, during the charging process, the high-voltage charger 110 may activate to provide a high-voltage charge current appropriate for all cells, as shown by box 206 of the flowchart. Box 208 of the flowchart of FIG. 4A indicates that, during the charging process, the individual low-voltage cell chargers 102 may activate to provide a low-voltage charge current to respective individual cells 104. Box 210 illustrates that, during the charging process, the BMS 108 continues to monitor the state of charge of the battery and individual cells 104, and control the operation of the high-voltage charger 110 and the individual low-voltage cell chargers 102.

As charging continues, the voltage of each individual cell 104 is monitored and compared to a predetermined upper voltage limit, as shown in decision box 212. In an embodiment of the invention, if the voltage of any individual cell 104 has not reached or exceeded a predetermined upper voltage limit, the high-voltage charger 110 and individual low-voltage chargers 102 continue charging, as shown in box 214, and monitoring of the state of charge of the battery and individual cells 104 continues (box 210).

If, however, the ongoing monitoring of the individual cells 102 indicates that one or more individual cells 104 has reached or exceeded a predetermined upper voltage limit, then the BMS 108 deactivates the high-voltage charger 110, as seen in box 216. In this event, the BMS 108 may also deactivate the individual low-voltage cell charger 102 associated with the one or more cells such as the cell 104 that has reached or

exceeded a predetermined upper voltage limit, as illustrated in box 218. Following deactivation of the high-voltage charger 110, and of the low-voltage individual charger 102 associated with the one or more cells such as the cell 104 that has reached or exceeded a predetermined upper voltage limit, the low-voltage individual chargers 102 associated with a number of cells such as the cell 104 that has not reached the predetermined upper voltage limit continue charging this number of cells. Also, the BMS 108 continues monitoring the state of charge of the battery and the individual cells such as the cell 104, and controlling the high-voltage charger 110 and low-voltage individual chargers 102, as shown by box 220.

If the ongoing monitoring by the BMS indicates that no additional cells that has reached a predetermined upper voltage limit, then charging by the individual low-voltage cell chargers 102 continues until another one or more of these cells such as the cell 104 reaches the predetermined upper voltage limit, as seen in decision box 222, and box 224.

If, however, as seen in decision box 222 of FIG. 5B, the continued cell monitoring indicates that at least one of the cells such as the cell 104 reaches or exceeds the predetermined upper voltage limit, then the BMS 108 deactivates the individual charger of the low-voltage individual charger 102 associated with the one at least cell such as the cell that has reached a predetermined upper voltage limit, as shown in box 226 of FIG. 5B. In an embodiment of the invention, low-voltage charging will continue for the number of cells that has not reached a predetermined upper voltage limit. That is, the one or more low-voltage individual chargers 102 will continue charging the associated at least one cell such as cell 104 that has/have not reached a predetermined upper voltage limit. As long as any one or more cells 104 continue to be charged in this fashion, as seen in decision box 228, the BMS 108 continues monitoring the state of charge of the battery and individual cells such as the cell 104, and continues deactivating the low-voltage individual charger 102 for any cell that reaches a predetermined upper voltage limit. Once the continued monitoring of the individual cell voltages indicates that all of the cells in the battery 106 have reached a predetermined upper voltage limit, and the individual cell charger 102 has been deactivated for each of

the cells such as the cell 104 in the battery 106 (i.e., no cells 104 are being charged), then the charging process ends, as seen in decision box 228 and box 230.

It is to be noted that the sequence of steps in the charging process described by the present invention is not limited to the sequence presented herein. Other
5 embodiments, sequences, and variations of the steps in the charging process described herein, are contemplated within the scope of the invention.

Individual Cell Charger

An individual cell charger and method of using it are disclosed. The voltage of each individual battery cell of a series connected cell configuration is measured. A
10 controlled power source charges the cells individually at an initial voltage. The voltage on each individual one of the charged cells is subsequently measured by a battery management system. The voltage of the controlled power source is incrementally increased to charge the cells individually at an incrementally higher voltage. The measuring and charging of each individual cell is repeated until the voltage on at least
15 one of the cells reaches a predetermined voltage. Once the voltage on at least one of the cells reaches a predetermined voltage, the measuring and charging each individual cell continues at substantially the same last incremental voltage.

According to an embodiment of the present invention, an individual cell charger is provided which is greatly simplified as compared with a conventional approach, partly
20 due to its integration with a Battery Management System, or BMS, resulting in a small, inexpensive component count.

A conventional BMS usually has the capability to measure the voltage of each individual cell in a multi-cell battery. Its usual function is to act on the monitored data to avoid over charging or over discharging any of the cells. It is this voltage measuring
25 capability that makes it useful when integrated with the present embodiment of the individual cell charger of the present invention.

An embodiment of the invention relates to an individual cell charger, which measures voltage increases on all of the cells and then charges alternating ones of a first set of the cells only. The charger then determines that voltage increases on all

cells are within predetermined limits. The charger then switches to alternating ones of a second set of the cells and charges them with a higher charging current. This cycle continues until at least one of these cells has reached the predetermined limit. The one or more cells having reached the predetermined limit are no longer charged, and the
5 remaining cells are continued to be charged at the last charging current. This charging cycle is continued until all of the cells reach the pre-determined limit.

By utilizing the disclosed embodiments of the invention, the individual cell charger ensures that each cell becomes fully charged during each charge cycle. According to the prior art, where the series connected cells were charged across the
10 entire series and not individually, individual cells could lag behind and never become fully charged. This is particularly true for lithium ion batteries. In this manner, the battery could be determined to be discharged prematurely due to the lagging cell not being fully charged, even though the remaining cells were not fully discharged and still capable of functioning. Also, such a lagging cell which does not become fully charged
15 during each charge cycle, may require early replacement.

Considering now the drawings with reference to FIG. 6, there is shown an individual cell charger 250 for charging a battery generally indicated at 251 having four cells 252, 254, 256 and 258 which are also designated A, B, C, and D, respectively, and which are connected in series. There may be a fewer or larger number of cells
20 employed. For example, the battery may comprise 16 cells to provide a 48 V pack. Each cell may be a lithium ion cell with an iron phosphate additive. Such a battery pack may be employed, for example, on a vehicle such as a neighborhood electric vehicle (not shown).

A direct current power source 261 supplies current through an H bridge switcher
25 263 under the control of a switcher control 264 to the primary winding 265 of a transformer 267. The switcher control 264 causes the duty cycle of the switcher 263 to create alternating current flowing through the primary 265 of the transformer 267. A secondary winding 269 of the transformer 267 is connected across a double rail pair of conductors 270 and 271 to provide alternating current to a set of capacitor coupled

bridge rectifiers 272, 274, 276 and 278 for supplying rectified current individually to the cells 252, 254, 256 and 258, respectively.

5 A battery management system (BMS) 279 measures the voltage on each cell during a charging operation and can selectively connect charging current to the cells by selectively coupling the charging current to individual ones of the cells or disconnecting or decoupling the charging current from cells reaching the predetermined voltages. A control signal lead 266 from the BMS 279 to the switcher control 264 causes the switcher 263 to increase or decrease its duty cycle incrementally. The BMS 279 may be similar to the battery management system disclosed in U.S. patent application No. 10 12/650,401, filed December 30, 2009, which is incorporated herein by reference.

Each one of the bridge rectifiers such as the bridge rectifier 272 is coupled between the double rail conductors 270 and 271 by capacitors such as a pair of capacitors 281 and 283 for the rectifier 272. The capacitors 281 and 283 are each preferably low effective series resistance capacitors, such as functional polymer 15 electrolytic capacitors. Each one of the bridge rectifiers such as the bridge rectifier 272 includes four diodes such as the diodes 285 through 288 for the bridge rectifier 272. Each bridge rectifier supplies energy to its cell such as the cell 252 (cell A) by a switch such as a switch 289 which are controlled by the battery management system 297 by ON/OFF CONTROL leads such as the lead 303. A pair of small current sense resistors 20 290 and 291 connect the bridge rectifier 272 to the cell 252.

A set of four low pass filters are provided for the four bridge rectifiers. The four low pass filters are similar to one another, and include a low pass filter 292 comprising a capacitor 293, resistor 294 and the resistor 305, for the bridge rectifier 272. The filtered output of bridge rectifier 272 is fed to the BMS 279.

25 The switcher 263 includes a set of four switches 295 through 298 connected in an H bridge configuration. A set of four diodes 299 through 302 are connected individually and are suitably poled across each one of the switches 295 through 298, respectively. The switcher control 264 selectively controls the switcher switches to alternately reverse current flow through the primary 265 of the transformer 267. For 30 example, when the switches 295 and 297 are activated and the other two switches 296

and 298 are deactivated, current flows from the DC power source 261 through the switch 295, through the primary 265 and the switch 297, and back to the power source 261. Thereafter, the switches 295 and 297 are switched off for a time, and then later switches 296 and 298 are turned on, to provide the alternating current flow through the winding 265. There will be inductive current in the winding 265 when the switches turn off, and it flows through the diode 302 to the winding 265 and back through the diode 300 to the power source 261 just after switches 295 and 297 turn off. Likewise, current flows through diode 301, winding 265 and diode 299 after switches 296 and 298 turn off.

As shown in FIG. 6, the cells A, B, C, and D represent cells that are discharged and ready to be charged. The "H Bridge" switcher 263 is connected to the DC power source 261 which could alternately be rectified and filtered mains or another DC source (not shown). The switcher 263 drives the primary 265 of transformer T_1 , the secondary 269 of which drives the parallel group of capacitor coupled bridge rectifiers, each corresponding to a cell in the series connected battery string. The capacitor coupling provides DC isolation of the winding from the different DC voltage levels of the cells.

The output of each bridge rectifier is fed through an off/on switch such as switch 289, and small value current sense resistors such as R_A and R_B (resistors 290 and 291, respectively), to its corresponding cell, such as cell A. It is also fed through the low pass filter such as the circuit including resistors R_{FA} , R_{FB} , and capacitor C_{FA} to the cell voltage monitoring terminals of a BMS.

When charging is not taking place, no current flows through the bridge rectifiers and the filtered cell voltages are fed through to the BMS so it can perform its normal cell monitoring function. When charging is taking place, however, the switcher feeds an AC signal into the primary winding of the transformer T_1 , causing an AC output on its secondary. The secondary voltages are AC coupled to the bridge rectifiers such as the rectifier 272 including diodes D_A , D_B , D_C , and D_D , causing rectified current such as I_1 to flow through them and through the cells such as cell A, providing it is switched on, thus charging the cell.

A concern, however, is that since all of the discharged cells may not be at the same voltage prior to charging, the lowest voltage cell limits the amplitude of the AC voltage from the transformer, and may draw current that is excessive, especially for the coupling capacitors and/or the bridge rectifiers. The disclosed embodiments of the present invention are designed to avoid, or at least greatly reduce this situation.

According to the method of the disclosed embodiments of this invention, prior to charging, the switcher 263 is off, and the BMS 279 monitors the voltage of all cells to establish a baseline. It then switches on alternate cells, such as cell A and C and then initiates the switcher 263 at its lowest or initial duty cycle by means of the switch control 264 in response to the control signal from the BMS 279 while monitoring the cells.

The BMS 279 then determines which, if any of the voltages have increased in voltage. An increase would occur if a current such as I_1 flowed from a cell's rectifiers through the small current sense resistors 290 and 291. The measured voltage, V_{1M} , would be the sum of the cell voltage V_1 plus the voltage drop across the current sense resistors caused by the charge current neglecting the internal cell resistance, which in this case is small by comparison. If the voltage increase is within a preset limit, then therefore the amount of charge current is satisfactory and the process is then repeated.

This time an alternate set of cells, such as cells B and D are switched on, and the cells A and C are switched off. It is then determined whether or not the voltage has increased within the preset limit, and the charge current is satisfactory. If in either case the voltage increase exceeds the limit, the BMS 279 concludes that a cell is faulty such as being shorted, and the BMS then stops the charge cycle, and provides a status indication.

The voltage limit is set by calculating a voltage increase based on a target value for cell charge current, such as I_1 , where $I_1 = (V_{1M} - V_1) / (R_A + R_B)$. It is assumed that no current flows into the BMS 279 through resistors R_{FA} and R_{FB} , and they therefore have no steady state influence on the measured voltage V_{1M} .

If the voltage increase is within the limit for both sets of cells, the BMS 279 increases the switcher duty cycle by one increment to increase the overall current flow, and repeats the above process. It continues to do so until the voltage increase of at

least one cell has reached the predetermined limit and therefore its current is at its predetermined limit.. Thereafter, as charging continues at that current level, the voltage on that cell continues to increase until it is close to a voltage on another. At that point, some of the charge current will begin to flow into other cells. Thus, the current in the first cell will start to decline. Subsequent measurements will detect that, and the charge current increases until at least one cell is being charged at its maximum current. This means that the maximum acceptable current is flowing into at least one cell, and no other cells are drawing excessive current.

The BMS 279 then turns on all cells, and charges at the last duty cycle setting for a predetermined period of time, preferably 5 seconds. After this charging has occurred, the cell voltages may have increased, so the charging is stopped and the cell voltages are again read to establish a new baseline.

Next, the switcher 263 is restarted at the same duty cycle that it left off and voltage increases are again measured in two groups, as before. If the increases are less than the maximum acceptable value, the duty cycle is incremented up again and measurements taken until at least one more cell reaches the maximum. If the increases are above the maximum value the duty cycle is decremented until they are all within the limit.

As the cycle is repeated, and the lowest voltage cell or cells become partially charged, the transformer voltage will be at successively higher values, and current begins to flow into other cells that had higher initial voltages, as well as continuing to flow into the cell or cells that initially had the lowest voltage. This process continues until the baseline voltages of all the cells are at the full charge value whereupon the charging algorithm is complete and charging stops. At this point the cells are also balanced.

In accordance with a presently preferred embodiment of the invention, the voltage increase measurements may be taken with pairs of alternate cells only, on at one time to avoid current flowing into an adjacent cell and causing an error. For example, in FIG. 6, if current I_2 flowed through cell B while a voltage increase measurement was being made for cell A, an error would occur since both I_1 and I_2

would determine the voltage drop across resistor R_B instead just I_1 alone. The voltages are measured through a low pass filter to average the voltage pulses caused by switcher current pulses. Although four cells are shown in the drawings, the concept is expandable to a larger or fewer number of cells.

5 While particular embodiments of the present invention have been disclosed, it is to be understood that various different modifications and combinations are possible and are contemplated within the true spirit and scope of the disclosed embodiments. There is no intention, therefore, of limitations to the exact disclosure herein presented.

10 Although the invention has been described with reference to the above examples, it will be understood that many modifications and variations are contemplated within the true spirit and scope of the embodiments of the invention as disclosed herein. Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which the invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated
15 drawings. Therefore, it is to be understood that the invention shall not be limited to the specific embodiments disclosed and that modifications and other embodiments are intended and contemplated to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

CLAIMS

1. An intelligent battery management system for mounting on board mobile equipment, comprising:

central stationary remote user access;

- 5 a battery pack having a series of cells mounted on mobile equipment for helping propel the equipment along the ground;

mobile battery management system mounted on board mobile equipment for facilitating battery management including, monitoring the state of charge of the battery pack;

- 10 wireless communication equipment for facilitating communication between the mobile battery management system and the central stationary remote user access;

a battery charger controlled by the battery management system for charging individual cells of the battery pack;

- 15 at least one sensor for monitoring load current from the battery pack and for supplying current data to the battery management system;

a load controller for facilitating load current in response to the battery management system; and

- 20 wherein the wireless communication equipment communicates the condition of the battery pack and the management of it to the remote user access.

2. The system according to claim 1, further including the battery management system including converters for monitoring individual cells of the battery pack.

3. The system according to claim 2, further including a temperature sensor for
25 monitoring the temperature of the cells, and a cell temperature measurement unit

responsive to the temperature sensor for measuring the temperature, voltage or current of individual cells.

4. The system according to claim 3, further including an operator control for an operator of the mobile equipment for receiving messages from the battery management system regarding the state of parameters of the cells.
5
5. The system according to claim 4, further including a part of the battery management system for supplying data, and a local display/keypad unit for receiving the data.
6. The system according to claim 4, further including a portable computer part of the battery management system.
10
7. The system according to claim 4, wherein the wireless communication equipment includes a wireless communication module for downloading data collected and stored by the battery management system.
8. An intelligent battery management system, comprising:
15
 - a battery pack having a series of cells;
 - a battery management system for facilitating battery management including monitoring the state of charge of the battery pack;
 - wireless communication equipment for facilitating communication between the battery management system to a remote location; and
 - 20 a battery charger controlled by the battery management system for charging individual cells of the battery pack.
9. The system according to claim 8, wherein the battery management system includes converters for monitoring individual cells of the battery pack.
10. The system according to claim 9, further including a temperature sensor for
25 monitoring the temperature of the cells, and a cell temperature measurement unit

responsive to the temperature sensor for measuring the temperature, voltage or current of individual cells.

11. The system according to claim 10, further including an operator control for use by an operator of the mobile equipment for receiving messages from the battery management system regarding the state of parameters of the cells.

12. The system according to claim 11, further including a part of the battery management system for supplying data, and a local display/keypad unit for receiving the data.

13. The system according to claim 11, further including a portable computer part of the battery management system.

14. The system according to claim 11, wherein the wireless communication equipment includes a wireless communication module for downloading data collected and stored by the battery management system.

15. A method of managing batteries employed on a number of vehicles, comprising: facilitating wireless communication between mobile battery management systems and a central stationary remote user access; using the remote user access to receive and send battery performance data.

16. A method according to claim 15, further including controlling, using the battery management system, either locally or remotely, a battery charger to prevent individual cells from exceeding a maximum voltage specification during charging.

17. A method for charging Lithium Ion batteries, such method comprising the steps of:

applying using a high voltage charger and or group of individual cell chargers, a charge current to a battery including a string of a plurality of battery cells connected in series, the charge current including a high-voltage component applied across the string of battery cells and a low-voltage component applied across each individual battery cell;

continually monitoring using a battery management system, the state of charge of each of the plurality of cells;

discontinuing the high-voltage component of current when one or more of the cells reaches a predetermined upper voltage limit;

5 discontinuing the low-voltage component of current to the one or more cells that has reached the predetermined upper voltage limit;

continuing to apply the low-voltage component of current to each of the plurality of cells that has not reached a predetermined upper voltage limit;

10 selectively discontinuing the low-voltage component of current to each of the plurality of cells that reaches a predetermined upper voltage limit.

18. The method according to claim 17, wherein using the battery management system, controlling the operation of the high-voltage charger and the individual low-voltage cell chargers, and continuing to monitor the state of charge of the cells during charging.

15 19. The method according to claim 18, wherein using the battery management system, monitoring the state of charge of the cells when the battery is not being charged.

20 20. The method according to claim 18, wherein using the battery management system, monitoring and comparing to a predetermined upper voltage limit, the voltage of each individual cell.

25 21. The method according to claim 20, during the continued charging of the cells, using the battery management system, deactivating the low-voltage individual charger associated with at least one cell reaches the predetermined upper voltage limit, and continuing charging the other remaining cells that have not reached the predetermined upper voltage limit.

22. The method according to claim 21, wherein determining using the battery management system, that all of the cells have reached their predetermined

upper voltage limit and all of the individual cell chargers have been deactivated, and then terminating the charging operation.

23. A method for charging a battery including a string of series connected cells, comprising:

5 charging the battery with a high voltage charger;

 detecting at least one of the cells being charged to a predetermined voltage by a battery management system;

 inhibiting the high voltage charger from further charging any of the cells in response to said detecting; and

10 charging individual ones of the cells by individual cell chargers, wherein all of the cells are continued to be charged, except the at least one of the cells.

24. The method according to claim 23, wherein using the battery management system, controlling the operation of the high-voltage charger and the individual low-voltage cell chargers, and continuing to monitor the state of charge of the
15 cells during charging.

25. The method according to claim 24, wherein using the battery management system, monitoring the state of charge of the cells when the battery is not being charged.

26. The method according to claim 24, wherein using the battery management
20 system, monitoring and comparing to a predetermined upper voltage limit, the voltage of each individual cell.

27. The method according to claim 26, during the continued charging of the cells, using the battery management system, deactivating the low-voltage individual charger associated with at least one cell reaches the predetermined upper
25 voltage limit, and continuing charging the other remaining cells that have not reached the predetermined upper voltage limit.

28. The method according to claim 27, wherein determining using the battery management system, that all of the cells have reached their predetermined upper voltage limit and all of the individual cell chargers have been deactivated, and then terminating the charging operation.

5 29. A system for charging batteries including a string of series connected cells, comprising:

a high voltage charger for charging the string of cells;

a group of individual cell chargers for charging individual ones of the cells;

10 a battery management system for detecting at least one of the cells being charged to a predetermined voltage, and then inhibits the high voltage charger from further charging any of the cells; and

wherein the individual cell chargers charge individual ones of the cells except the at least one cell charged to the predetermined voltage.

15 30. A battery charging system for charging a Lithium Ion battery including a string of individual battery cells connected in series, comprising:

a battery management system,

a high-voltage battery charger connected electrically across the string of series connected cells;

20 a plurality of low-voltage battery cell chargers, wherein the number of low-voltage battery chargers equals the number of cells in a battery being charged by the system, and each low-voltage charger is in electrical communication with one of the battery cells;

25 wherein, a charge current is applied to the battery, the charge current including a high-voltage charging current component that is generated by the high-voltage battery charger and applied through the string of cells, and a low-

voltage charging current component generated by each low-voltage battery charger and applied through each individual battery cell monitoring;

the battery management system continually monitoring the voltage of each individual cell;

5 wherein the battery monitoring system discontinues the high-voltage component of the charge current when at least one of the battery cells reaches a predetermined upper voltage limit;

10 the battery management system discontinues the low-voltage component of the charge current to the at least one of the battery cells having reached the predetermined upper voltage limit;

the low-voltage battery chargers continue to apply charge to the battery cells that have not reached the predetermined upper voltage limit; and

15 wherein the battery management system discontinues the low-voltage charge current to each of the plurality of battery cells when the battery cells have reached the predetermined upper voltage limit.

31. A method of charging series connected battery cells individually, comprising:

measuring voltages on all of the cell;

charging from a source of power alternating ones of a first set of these cells only;

20 determining using a battery management system that voltage increases on all cells are within predetermined limits;

switching the power source using a switcher to the alternating ones of a second set of the cells;

25 charging from the source of power the second set of the cells with a higher charging current; and

charging all of these cells until at least one of these cells has reached the predetermined limit at the last value of the charging current.

32. The method according to claim 31, wherein when the voltage on at least one of the cells is determined to exceed the predetermined limit, indicating that the at least one cell is faulty.

33. An individual cell battery charger for charging a group of series connected battery cells, comprising:

a controlled power source for supplying charging current to the cells to be charged;

a plurality of switches to connect the charging current to individual ones of the cells;

a battery management system for selectively interconnecting the controlled power source to selected ones of the cells; and

wherein the battery management system measures the voltage on each one of the cells and increases the charging current from the controlled power source incrementally until the voltage on all of the cells reaches a predetermined voltage; and

wherein the battery management system causes the switches to connect selectively, alternate ones of the cells to the controlled power source.

34. An individual cell battery charger according to claim 33, wherein the battery management system causes the controlled power source to maintain its charging current constant once at least one of the cells reaches a predetermined voltage until all of the cells reach the predetermined voltage.

35. An individual cell battery charger according to claim 34, wherein the battery management system causes the controlled power source to decrement its charging current when the voltage on at least one of the cells reaches the

predetermined voltage and continues to cause the cells to be charged with the decremented charging current.

36. An individual cell battery charger according to claim 34, wherein the battery management system causes an indication that at least one cell is faulty when the charging current exceeds the predetermined voltage.

37. An individual cell battery charger according to claim 33, wherein the controlled power source includes a group of rectifiers corresponding to individual ones of the cells, and a transformer for supplying alternating current to the rectifiers, a bridge switches for generating the alternating current for the transformer.

38. An individual cell battery charger according to claim 37, wherein the controlled power source includes a switcher control to cause the bridge switcher to change the duty cycle of the switching rate thereof.

39. A method of charging individually a group of series connected battery cells, comprising:

measuring the voltage on each individual one of the cells;

charging the cells individually using a controlled power source at an initial voltage;

subsequently measuring the voltage on each individual one of the charged cells;

increasing the voltage of the controlled power source incrementally;

charging the cells individually at an incrementally higher voltage using the controlled power source;

repeating the measuring and charging of each individual one of the cells until the voltage on at least one of them reaches a predetermined voltage;

subsequently repeating the measuring and charging each individual one of the cells at the last incremental voltage of the controlled power source until the voltage on all of the cells reaches the predetermined voltage, unless the voltage on at least one of the cells exceeds the predetermined voltage; and

- 5 subsequently repeating the measuring and charging each individual one of the cells at an incrementally lower voltage of the controlled power source until the voltage on all of the cells reaches the predetermined voltage.
40. The method according to claim 39, wherein providing an indication that at least one of the cells is faulty if the charging current thereto exceeds a
10 predetermined level.
41. An individual cell battery charger according to claim 39, wherein the battery management system causes the controlled power source to maintain its charging current constant once at least one of the cells reaches a predetermined voltage until all of the cells reach the predetermined voltage.
- 15 42. An individual cell battery charger according to claim 41, wherein the battery management system causes the controlled power source to decrement its charging current when the voltage on at least one of the cells reaches the predetermined voltage and continues to cause the cells to be charged with the decremented charging current.
- 20 43. An individual cell battery charger according to claim 41, wherein the battery management system causes an indication that at least one cell is faulty when the charging current exceeds the predetermined voltage.
- 25 44. An individual cell battery charger according to claim 39, wherein the controlled power source includes a group of rectifiers corresponding to individual ones of the cells, and a transformer for supplying alternating current to the rectifiers, a bridge switches for generating the alternating current for the transformer.

45. An individual cell battery charger according to claim 44, wherein the controlled power source includes a switcher control to cause the bridge switcher to change the duty cycle of the switching rate thereof.

46. An individual cell charger for charging individually a group of series connected battery cells, comprising:

means for measuring the voltage on each individual one of the cells;

means for charging the cells individually using a controlled power source at an initial voltage;

means for subsequently measuring the voltage on each individual one of the charged cells;

means for increasing the voltage of the controlled power source incrementally;

means for charging the cells individually at an incrementally higher voltage using the controlled power source;

means for repeating the measuring and charging of each individual one of the cells until the voltage on at least one of them reaches a predetermined voltage;

means for subsequently repeating the measuring and charging each individual one of the cells at the last incremental voltage of the controlled power source until the voltage on all of the cells reaches the predetermined voltage, unless the voltage on at least one of the cells exceeds the predetermined voltage; and

means for subsequently repeating the measuring and charging each individual one of the cells at an incrementally lower voltage of the controlled power source until the voltage on all of the cells reaches the predetermined voltage.

47. The charger according to claim 46, wherein providing an indication that at least one of the cells is faulty if the charging current thereto exceeds a predetermined level.

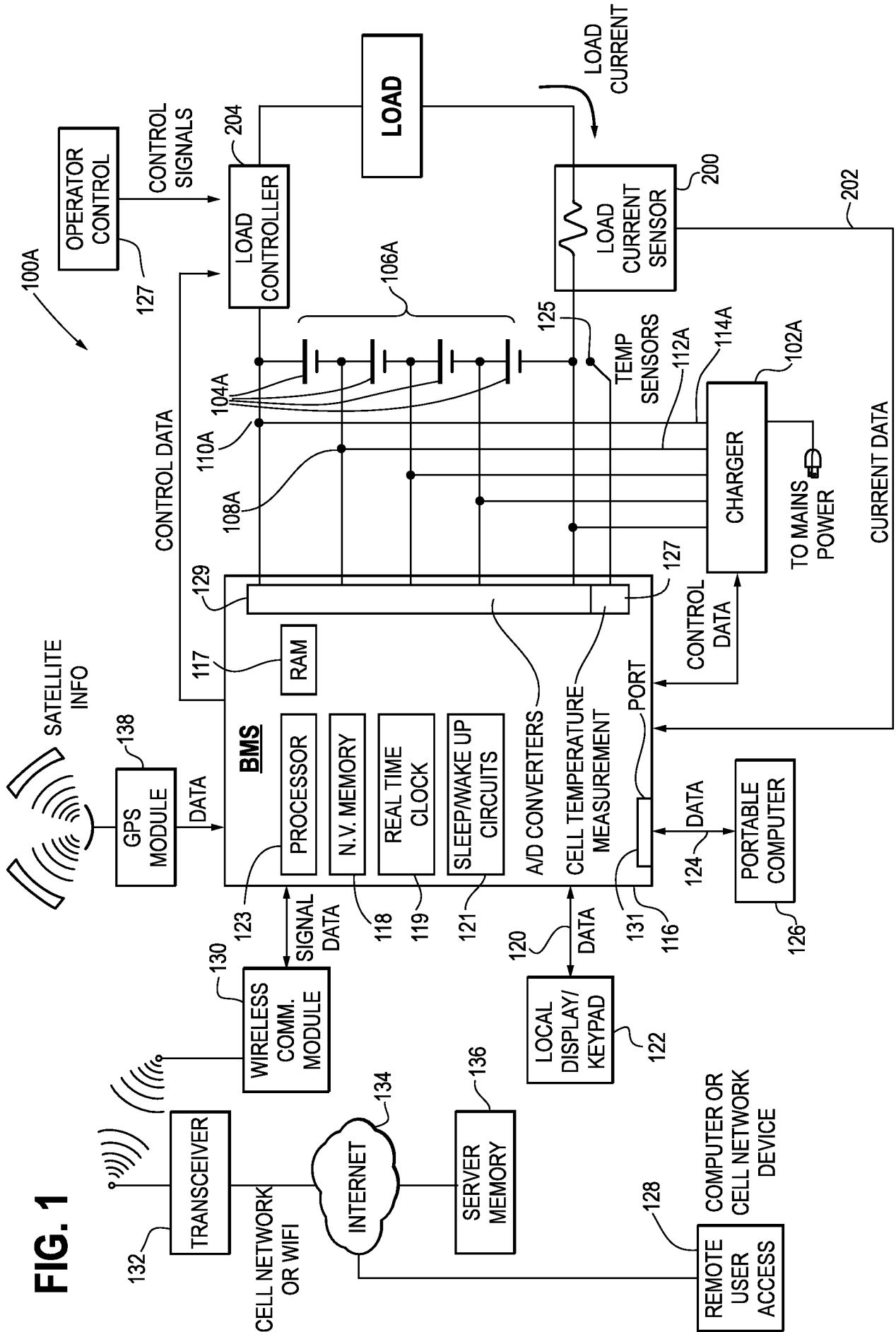


FIG. 1

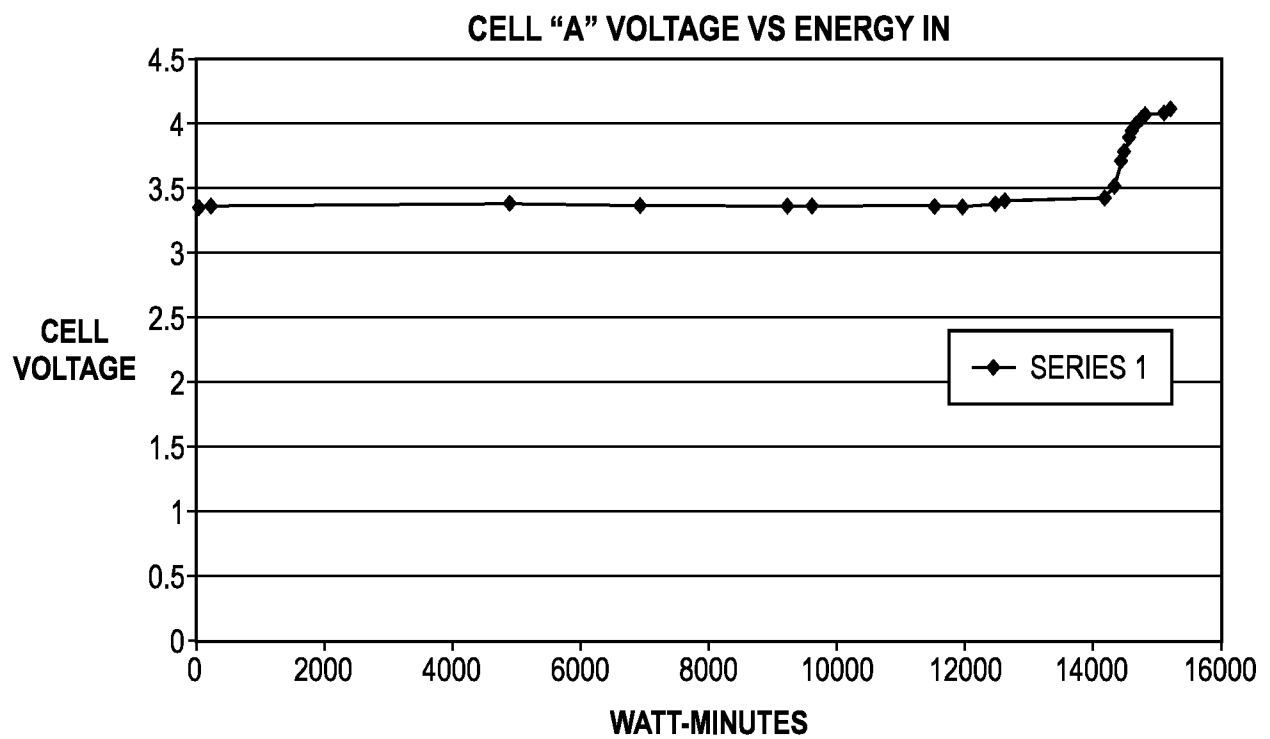
FIG. 2

FIG. 3
PRIOR ART

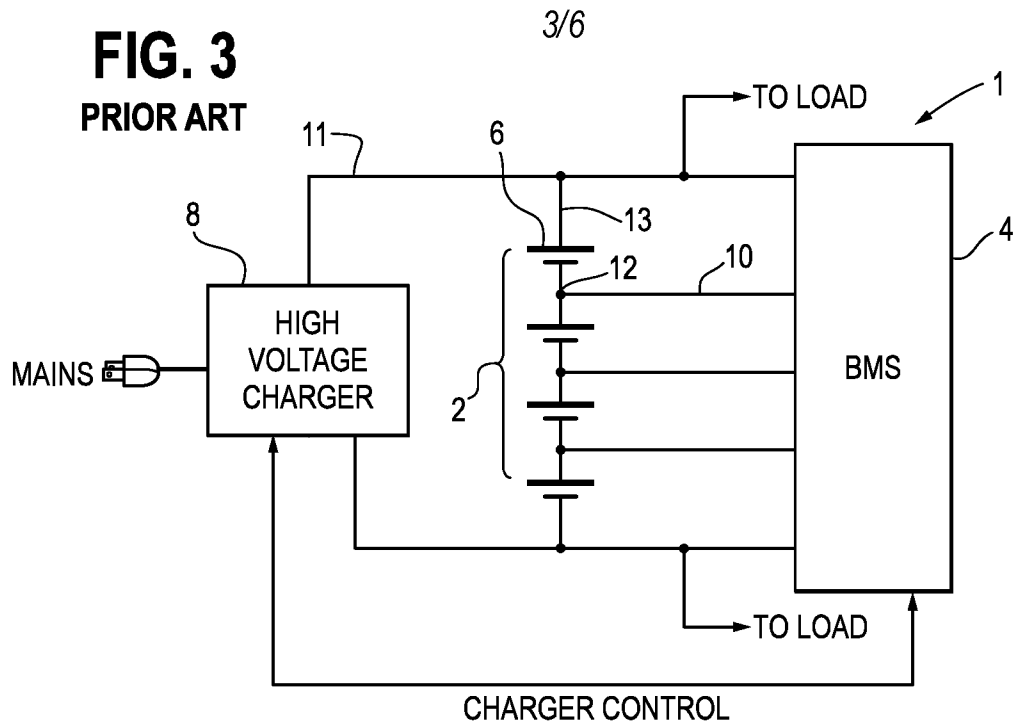
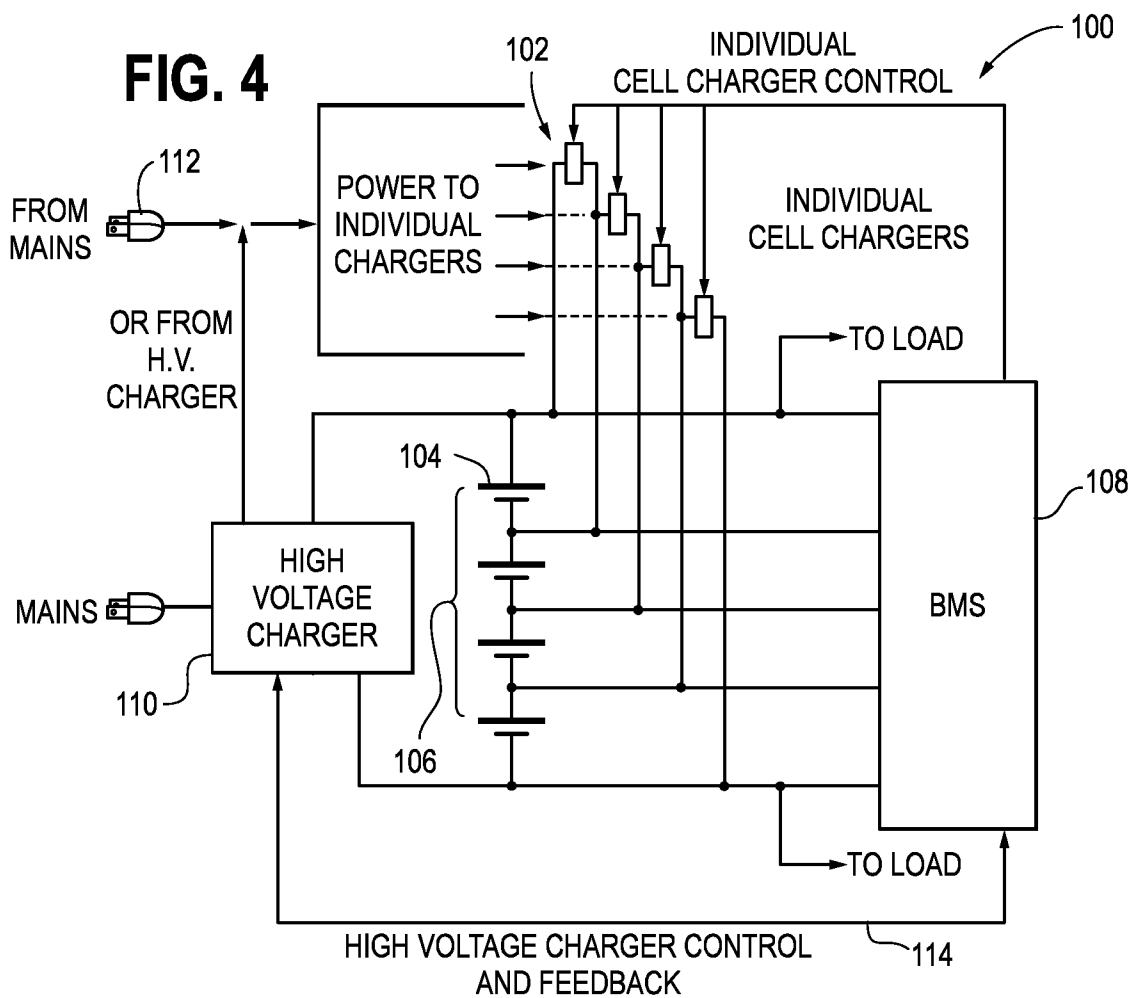
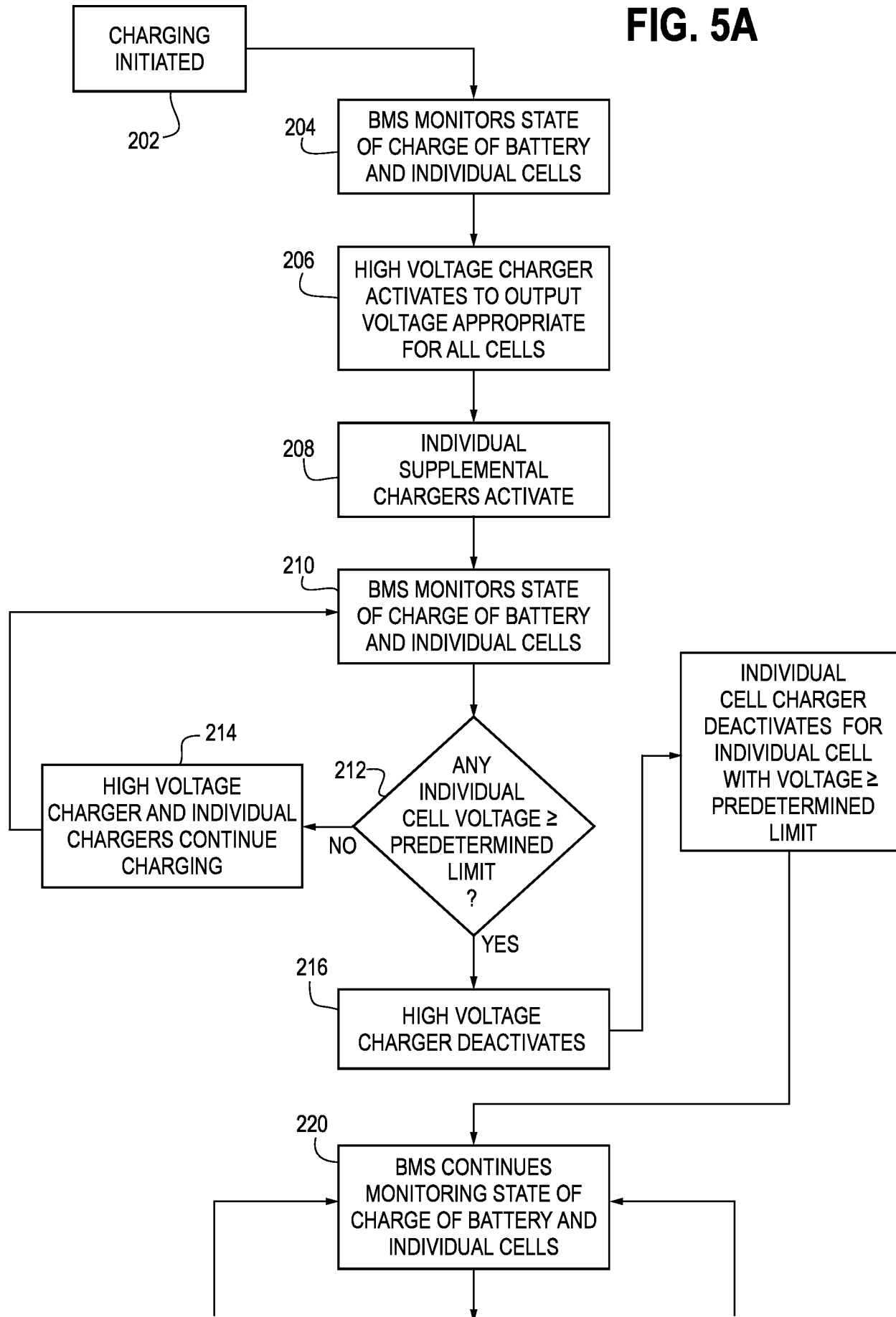


FIG. 4



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FIG. 5A



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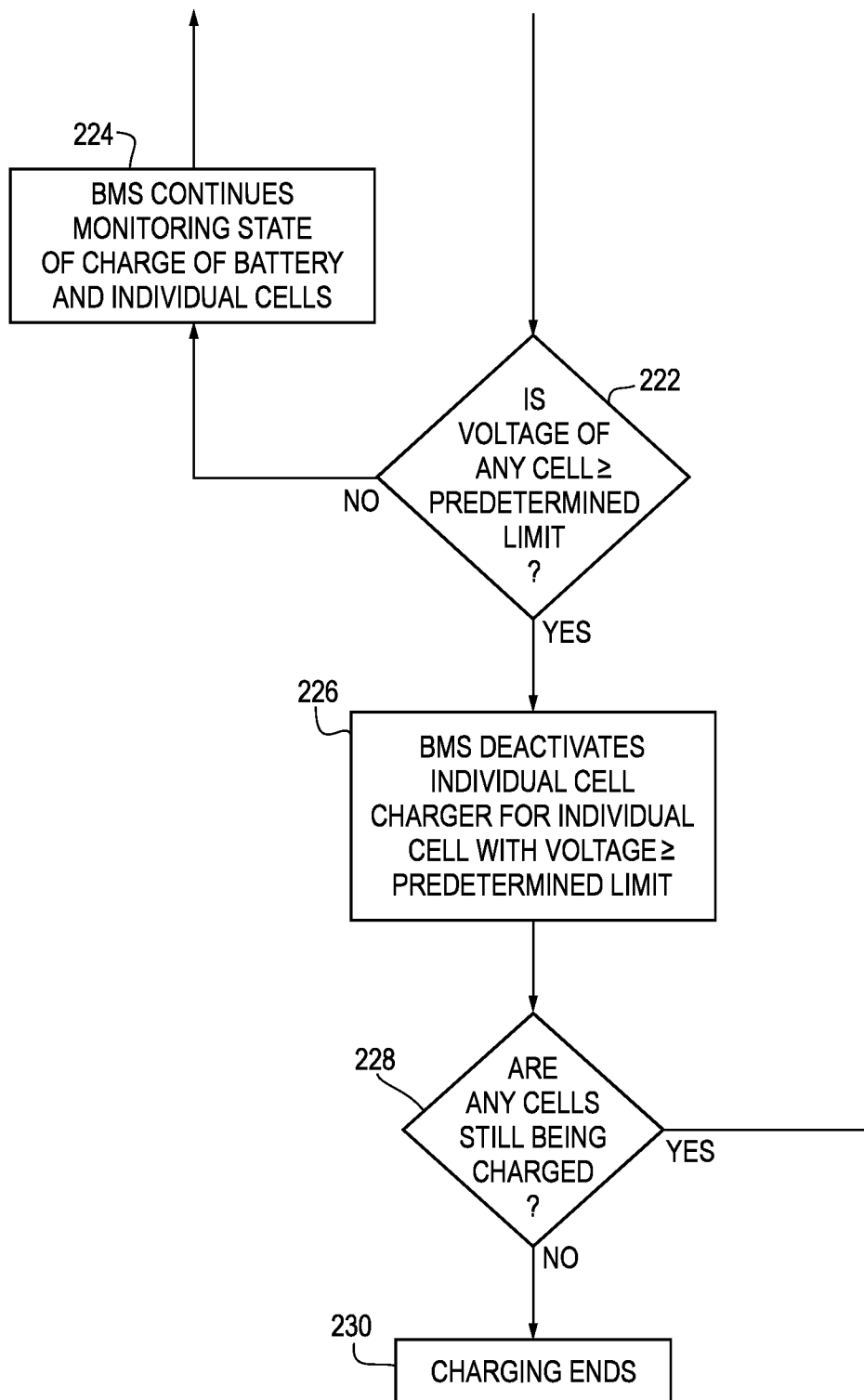
FIG. 5B

FIG. 6

