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(54) Title: BATTERY MANAGEMENT SYSTEM FOR PARALLEL CHARGING OF BATTERY MODULES

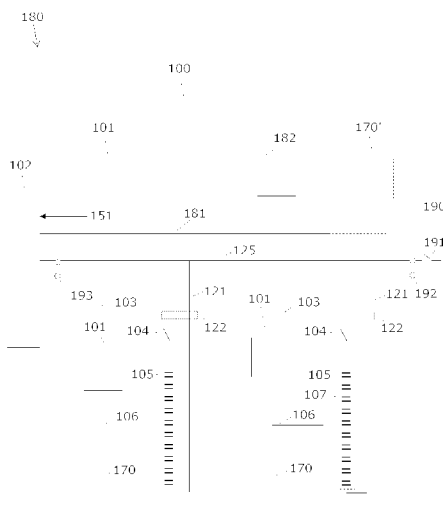


Fig. 1A

(57) **Abrégé/Abstract:**

The invention relates to a battery system which includes a master controller (101) arranged to determine a current control signal for controlling a charging current from a current source (102), one or more battery modules (103) comprising battery module terminals, a connection arrangement (121) arranged to electrically connect the one or more battery modules in parallel via the battery module terminals to enable parallel charging/discharging via individual switches (104), where each battery module comprises at least one battery cell (105), and a slave control unit (106) configured to monitor a battery condition of the battery module and to determine a battery event based on the battery condition, where the master controller is configured to determine the current control signal dependent on the battery event from any of the battery modules so as to cause a reduction or increase of the charging current, and to determine the current control signal dependent on battery module capacities of the one or more battery modules.

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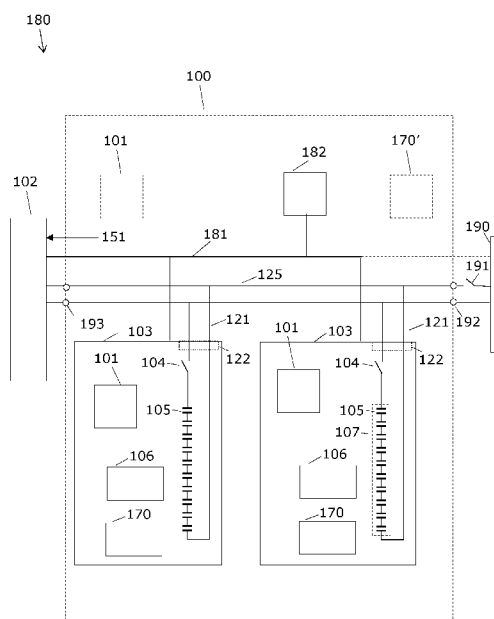


Fig. 1A

(57) **Abstract:** The invention relates to a battery system which includes a master controller (101) arranged to determine a current control signal for controlling a charging current from a current source (102), one or more battery modules (103) comprising battery module terminals, a connection arrangement (121) arranged to electrically connect the one or more battery modules in parallel via the battery module terminals to enable parallel charging/discharging via individual switches (104), where each battery module comprises at least one battery cell (105), and a slave control unit (106) configured to monitor a battery condition of the battery module and to determine a battery event based on the battery condition, where the master controller is configured to determine the current control signal dependent on the battery event from any of the battery modules so as to cause a reduction or increase of the charging current, and to determine the current control signal dependent on battery module capacities of the one or more battery modules.

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BATTERY MANAGEMENT SYSTEM FOR PARALLEL CHARGING OF BATTERY MODULES

FIELD OF THE INVENTION

- 5 The invention relates to battery charging systems, particularly to battery charging systems for automatic charging of multiple battery modules arranged in a battery system.

BACKGROUND OF THE INVENTION

- 10 Battery powered machines like floor-cleaning machines may comprise a battery system which can include one or more battery modules. In some situations, where two or more battery modules are included in the battery system, the battery modules may have different performance characteristics. The different performance characteristics may be due to different cell capacity, different charge
15 cut-off, different impedance, different cell technology, different age and other.

Efficient charging of such battery modules having different performance characteristics may be a challenge. Particularly, fast, reliable and safe charging of such battery modules may not be achievable with existing battery management
20 systems.

EP 2 575 235B1 discloses a system for controlling the charging and discharging of one or more battery packs or battery modules connected to a power source or an apparatus driven by the battery packs. Each battery pack comprises a number of
25 battery cells connected to two or more terminals for establishing an electrical connection with the power source or the apparatus. The electronic system for controlling the charging of the battery pack and the electronic system for controlling the operation of the apparatus are integrated into the battery pack (8). The battery pack comprises a communications interface for communicating with
30 other battery packs and generates a charging and discharging pool, where the most effective battery pack to charge or discharge is charged or discharged first.

Thus, EP 2 575 235B1 discloses a system where the battery modules are charged or discharged one by one.

SUMMARY

It is an object of the invention to improve battery charging systems to alleviate one or more of the above-mentioned problems, and therefore to provide a battery management system capable of providing fast but still reliable and safe charging
5 of a battery system which may consist of battery modules with different battery characteristics.

In a first aspect of the invention there is provided a battery module comprising
- at least one battery cell,

- 10 - a battery module terminal arranged to detachably connect with a connection arrangement, where the connection arrangement is arranged to electrically connect a plurality of the battery modules in parallel to enable parallel charging/discharging via individual switches,
- a master controller arranged to determine a current control signal for controlling
15 and adjusting a charging current from a current source,
- a slave control unit configured to monitor a battery condition of the battery module, where the slave control unit and/or the master controller is arranged to determine a battery event based on the battery condition, where the master controller is configured to
20 - determine the current control signal dependent on the battery event so as to cause a reduction or increase of the charging current, and to determine the current control signal dependent on battery module capacities of the one or more battery modules being connected to the current source via the individual switches.

- 25 When two or more battery modules are connected in parallel via the battery system connector, each slave control unit of the battery modules are capable of generating battery conditions which could generate a battery event. Since the current control signal is determined based the battery event from any battery module, the reduction of the current is adapted dependent on any of the parallel
30 charged or discharged battery module. Advantageously, the adjustment of the charging current supplied to the parallel connected battery modules dependent on battery events from any of the battery modules will optimize charge performance of each module.

Advantageously, since the battery modules are charged in parallel, with a suitable charging power, it may be possible to improve the charging speed compared with a system where battery modules are charged sequentially one by one, due to the limited maximal charging current of a single battery module. The improved
5 charging speed may be achieved while reliability and safety are maintained since the charging current is adjustable and dependent on any battery event.

While the reduction of the charging current is dependent on the battery event, increases may be independent on the battery event but dependent on other
10 conditions such as dependent on a timer signal or dependent on an allowed time condition. Alternatively, the master controller may be configured to determine the current control signal dependent on the battery event so as to cause an increase of the charging current. For example, changes in the battery module temperature could generate a temperature-based battery event which could allow an increase
15 of the charging current.

Increase or reduction of the charging current may comprise corresponding changes in the charging current dependent on predetermined changes or changes which are determined according to predetermined rules. The adjustments may be
20 performed according to predetermined times where current adjustments are allowed.

The battery condition may comprise a battery module temperature, a cell voltage of the at least one battery cell, a battery module voltage measured over the at
25 least one battery cell, a battery module charging current flowing into one of the battery modules and/or a comparison result of the battery module charging current or the charging current, or derivatives thereof, with a current threshold. For example, a derivative of the module charging current or the charging current in the form of a time average may be compared with a current threshold for
30 accessing a fully charged condition of the battery module.

The term "battery event" is meant to denote a measurement of a battery condition or battery parameter outside a specified range. Thus, a battery event is an indication or warning that at least one battery condition or battery parameter
35 exceeds or lies below a predetermined range. Battery events may relate to any

appropriate battery parameter, such as e.g. voltage, current, temperature, or state of charging of battery modules.

Thus, as an example, a battery event may be determined in response to one or
5 more of:

- determining a maximum cell voltage event when the cell voltage has reached a maximum voltage,
- determining a fully charged battery module event indicating that the battery module is fully charged, and
- 10 - determining a maximum battery module charging current event when the battery module charging current exceeds a maximum current.

As another example, a battery event may be determined in response of determining that the battery module voltage is below a given voltage limit, is
15 within a given voltage range or is the lowest battery module voltage among other battery modules voltage. This battery event may be used during an initial charging process where battery modules may be charged individually or in groups dependent on the battery module voltages in order to equalize battery module voltages among the connected battery modules. For example, the battery
20 modules with the lowest module voltage is connected to the current source first. The other modules, i.e. the battery modules which are not connected to begin with, are connected in parallel with the first-connected modules automatically when the modules voltages of the initially connected modules reach the voltage level of modules with higher module voltages.

25 Any appropriate battery condition relevant to the battery module and/or the charging thereof may be specified to lie within a predetermined range, and a battery event may be provided in the case where the battery condition lies outside the predetermined range.

30 It should be noted, that the battery module comprises both a slave control unit as well as a master controller. However, the battery module may be part of a battery system with more battery modules and/or in a battery system with a separate master controller. In the case, where the battery system comprises more than

one master controller, one of the master controllers is appointed as the active master controller, whilst the other(s) is/are passive.

According to an embodiment a magnitude of the reduction or the increase of the charging current is determined dependent on the battery module capacities of said one or more battery modules. Advantageously, the magnitude of the charging current is adapted dependent on the remaining capacity of the parallel connected battery modules so that the charging current matches the allowed total charging current of the still not fully charged battery modules.

10

According to an embodiment, the master controller is configured to determine the current control signal so as to cause and possibly continue the increase of the charging current only in the absence of the battery event. Advantageously, the battery events, which require a reduction of the charging current may be

15 prioritized over current increases. This may prevent too high charging currents. Thus, according to this embodiment, the system may be configured so that only current decreases are determined dependent on battery events, while current increases may be dependent on other conditions.

20 According to an embodiment, the master controller is configured to determine the current control signal dependent on a timer signal so that changes of the current control signal is only possible at times given by the timer signal. Advantageously, both increases and decreases in the charging current, are only possible at allowed times or allowed periods of time, so that decreases in the charging current can

25 prioritized over charging current increases

According to an embodiment, the slave controller is configured to determine a fully charged condition of one of the battery modules dependent on a comparison of the charging current with a current threshold or to determine the fully charged condition when all cell voltages of the battery cells in the battery module has

30 reached a maximum voltage.

According to an embodiment the battery module comprises one of the switches. Advantageously, the switches are comprised by the battery modules, i.e. so that

35 each battery module houses a switch. In case the switches were arranged

externally to the battery modules, the switches would have to be dimensioned according to a worst-case scenario of the possible different types (e.g. with different load characteristics) of battery modules that are allowed to be connected, e.g. so that the switches are dimensioned to a maximum charge and
5 discharging current of the battery modules which are allowed to be connected to the connection arrangement.

In case of internal switches, the internal switch in each battery module need only be dimensioned to fit the maximum charge and discharge current of the module.
10

According to an embodiment, the switch is controllable to connect or disconnect the battery module from the current source or a load. Advantageously, the switch may be controllable via control signals from the master controller and/or the slave control unit.

15

A battery module according to any of the preceding claims, wherein upon detection of a battery event, the reduction of the charging current is: a first predetermined percentage of the total battery cell capacity of the battery module, or a second predetermined percentage of the maximum charging current of the
20 current source; whichever reduction is the smallest. Thus, when a battery is detected, the charging current is decreased by the smaller of the first predetermined percentage of the total battery cell capacity of the battery module and the second predetermined percentage of the maximum charging current of the current source.

25

In an embodiment, upon no detection of a battery event for a predetermined amount of time, the increase of the charging current is: a third predetermined percentage of the total battery cell capacity of the battery module, or a fourth predetermined percentage of the maximum charging current of the current
30 source; whichever increase is the smallest. Thus, when no battery event is detected for a predetermined amount of time, the charging current is increased by the smaller of the third predetermined percentage of the total battery cell capacity of the battery module and the fourth predetermined percentage of the maximum charging current of the current source. The charging current is thus increased by
35 a third predetermined percentage, e.g. 1%, of the accumulated nominal capacity

of all active battery modules or by a fourth predetermined percentage, e.g. 1%, of the charger's maximum charging current, whatever is smallest. The charge current is typically increased at predefined time intervals, such as every 100 mS, unless an event has occurred.

5

It should be noted that the nominal value of the first, second, third and fourth predetermined percentage may be similar. Thus, for example the first and second predetermined percentages equal e.g. 8%, 7%, 6% or 5%, whilst for example, the third and fourth predetermined percentages equal 1% or 2%. Typically, the
10 third and/or fourth predetermined percentages are smaller than the first and/or second predetermined percentage, since it is advantageous that the reduction of charging current is relatively large, and the increase of the charging current is relatively smaller. The increase and reduction of the charging current upon detection of a battery event and the lack of a battery event, respectively, depends
15 upon both the battery cell capacity within the battery module and the capacity of the current source, since this limits the variations in charging current.

A second aspect of the invention relates to a battery system comprising
- a master controller arranged to determine a current control signal for controlling
20 and adjusting a charging current from a current source (102),
- one or more battery modules (103) comprising battery module terminals (122),
- a connection arrangement (121) arranged to electrically connect the one or more battery modules (103) in parallel via the battery module terminals (122) to enable parallel charging/discharging via individual switches (104), where each
25 battery module comprises
- at least one battery cell,
- a slave control unit configured to monitor a battery condition of the battery module and to determine a battery event based on the battery condition, where the master controller is configured to
30 - determine the current control signal dependent on the battery event from any of the battery modules so as to cause a reduction or increase of the charging current, and to determine the current control signal dependent on battery module capacities of the one or more battery modules being connected to the current source or via the individual switches.

35

It should be noted, that the battery system may comprise only one battery module. In this case, the single battery module comprises an active slave control unit as well as an active master controller.

- 5 Some of the advantages of the battery system are already described in relation to the description of battery modules. In general, it is advantageous that the battery system is adaptive, dynamic and self configuring. The battery system can function with one or a plurality of battery modules, and the number of battery modules need not be known to the battery system prior to charging/discharging.
- 10 Moreover, the number of battery modules may change during the charging/discharging; for instance, if the battery module containing the active master controller stops functioning or if an extra battery module is added, the battery system will decide on which battery module to subsequently operate as active mater controller. Moreover, newer and older battery modules may be mixed
- 15 and charged at the same time in the battery system. Thus, the battery system of the invention is a flexible and dynamically adaptive battery system.
- When two or more battery modules are connected in parallel via the battery system connector, each slave control unit of the battery modules are capable of generating battery conditions which could generate a battery event. Since the
- 20 current control signal is determined based the battery event from any battery module, the reduction of the current is adapted dependent on any of the parallel charged or discharged battery module. Advantageously, the adjustment of the charging current supplied to the parallel connected battery modules dependent on battery events from any of the battery modules will optimize charge performance
- 25 of each module.

Advantageously, since the battery modules are charged in parallel, with a suitable charging power, it may be possible to improve the charging speed compared with a system where battery modules are charged sequentially one by one, due to the

30 limited maximal charging current of a single battery module. The improved charging speed may be achieved while reliability and safety are maintained since the charging current is adjustable and dependent on any battery event.

According to an embodiment, each of the battery modules comprises a digital

35 processor which is configurable to operate as the master controller.

Advantageously, the processor used for operating the slave control units may also operate the master controller.

According to an embodiment, the configuration to operate as the master controller
5 is determined dependent on individual data stored by each of the battery modules.

According to an embodiment, the battery system comprises a register which stores identification data obtained from each of the battery modules and wherein
10 the master controller is configured to store charging data in the register indicating a fully charged and/or discharge condition of the battery modules.

According to an embodiment, the battery system comprises a communication function, such as a CAN bus, arranged to communicate information, such as the
15 battery event, battery identification or status, from the slave control unit to the master controller and to communicate the current control signal to the current source.

According to an embodiment, the master controller is configured to request
20 battery modules individually to connect to the current source dependent on battery module voltages obtained from the one or more battery modules, where the battery module voltage is a voltage over the series connected battery cells. Advantageously, by selectively charging one or more battery modules dependent on their battery module voltages, the battery module voltages of all battery
25 modules can be equalized before all battery modules are electrically connected in parallel. For example, during an initial charging process where battery modules may be charged individually or in groups dependent on the battery module voltages in order to equalize battery module voltages among the connected battery modules. For example, the battery modules with the lowest module
30 voltage is connected to the current source first. The other modules, i.e. the battery modules which are not connected to begin with, are connected in parallel with the first-connected modules automatically when the modules voltages of the initially connected modules reach the voltage level of modules with higher module voltages.

According to an embodiment of the battery system, upon detection of a battery event, the reduction of the charging current is: a fifth predetermined percentage of the total battery cell capacity of the battery modules of the battery system, or a sixth predetermined percentage of the maximum charging current of the current source; whichever reduction is the smallest.

According to an embodiment of the battery system, upon no detection of a battery event for a predetermined amount of time, the charging current is increased: a seventh predetermined percentage of the total battery cell capacity of the battery modules of the battery system, and an eighth predetermined percentage of the maximum charging current of the current source; whichever increase is the smallest.

It should be noted, that the term "total actual battery capacity" is meant to denote the battery capacity of the active battery modules 103 of the battery system 100. An "active" battery module 103 is a battery module 103 having a closed switch 104. A battery module having battery cells in the process of being charged is thus an active battery module.

A third aspect of the invention relates to a battery powered apparatus, such as a floor cleaning machine, comprising the battery system of the second aspect and a load, such as an electrical motor drive, where the apparatus including the load is arranged to be powered by the battery system.

A fourth aspect of the invention relates to a battery-charger system comprising the battery system of the second aspect and the current source.

A further aspect of the invention relates to a method for charging a battery system, where the battery system comprises

- a master controller arranged to determine a current control signal for controlling and adjusting a charging current from a current source,
- one or more battery modules comprising battery module terminals,
- a connection arrangement arranged to electrically connect the one or more battery modules in parallel via the battery module terminals to enable parallel charging/discharging via individual switches, where each battery module comprises

- at least one battery cell,
 - a slave control unit configured to monitor a battery condition of the battery module and to determine a battery event based on the battery condition, where the method comprises:
 - 5 - determining the current control signal dependent on the battery event from any of the battery modules so as to cause a reduction or increase of the charging current, and
 - determining the current control signal dependent on battery module capacities of the one or more battery modules being connected to the current source or via
- 10 the individual switches.

In general, the various aspects and embodiments of the invention may be combined and coupled in any way possible within the scope of the invention. These and other aspects, features and/or advantages of the invention will be

15 apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be described, by way of example only, with

20 reference to the drawings, in which

- Fig. 1A shows a battery-charger system comprising a battery system with two battery modules,
- Fig. 1B shows a battery-charger system comprising a battery system with only
- 25 one battery module,
- Fig. 2A shows the maximal charging current of a battery module as a function of temperature,
- Fig. 2B shows voltage and current as a function of time in a charging process,
- Fig. 3 shows an example of an event-controlled charging process with two battery
- 30 modules,
- Fig. 4 provides an overview of some battery events, and
- Fig. 5 is a flow diagram over a method to determine the master controller.

DESCRIPTION OF EMBODIMENTS

Fig. 1A and 1B show a battery-charger system 180 comprising a battery system 100 and a current source 102 arranged to supply a charging current to one or more battery modules 103 of the battery system 100. The current source 102 is
5 controllable to adjust the charging current dependent on the current control signal 151 from a master controller 101. The current source 102 is connectable to the battery system 100 via terminals 193. However, it should be noted that the battery system 100 may be arranged to be connected substantially continuously to the current source 102, e.g. when the current source 102 is part of an onboard
10 charger. In such cases, the terminals 193 may be expendable.

Even though fig. 1A and 1B also show a load 190, it should be noted that the load 190 connected via load terminals 192 to the battery-charger-system 180 or to the battery system 100 is not part of the battery-charger system 180 itself. Instead,
15 the battery charger system 180 and the load 190 with an optional switch 191 forms a battery powered apparatus, where the apparatus is arranged to be powered by the battery system 100.

Each battery module 103 comprises one or more battery cells 105 which are
20 arranged in series. The connected battery cells 105 of a battery module constitutes a core-pack 107.

A function of the master controller 101, which is comprised by the battery system 100, is to determine the current control signal 151, which could be implemented
25 in the communication bus 181, for controlling and adjusting a charging current from the current source. The current control signal 151 may be a digital or analogue control signal. For example, the current control signal 151 may be in format which is compatible with a communication bus format such as a CAN bus format. The current control signal may contain information, e.g. a digital or
30 analogue value, which directly specifies the desired charging current, or the current control signal may indirectly specify the desired charging current, e.g. by specifying a change in the charging current or by including information which is translated by the current source, e.g. via a predetermined look-up table, into the desired charging current.

The current source 102 may be an electronically controllable power supply which can deliver a DC current according to the current control signal 151. The voltage amplitude at the output of the current source 102 may be controlled to a desired voltage level, e.g. a constant or substantially constant voltage. The current may
5 be controllable e.g. in a range from zero or substantially zero to 735 A, such as up to 1000 A, for a system with up to 25 battery modules.

The battery system 100 comprises a connection arrangement 121, principally illustrated in Fig. 1A and 1B, arranged to establish electrical connection with
10 battery module terminals 122 of the battery modules so that the input/output current terminals of the battery modules 103 are parallel connected with the current supply terminals of the current source 102.

In addition to the electrical connectors, the connection arrangement 121 may
15 comprise mechanical structures such as guides to ensure that battery modules are not connected with reverse polarity. Other mechanical connections of the battery modules are possible such as bolted connections.

The parallel connection between the battery modules may be established via a
20 power bus 125 which connects all connection arrangements 121 in parallel with the current source 102 and with the load 190 or the load terminals 192 of the battery system 100.

In an example the battery module terminals 122 may be connection terminals
25 such as threaded terminals which are detachably connectable with corresponding connection terminals of the connection arrangement 121. The connection arrangement 121 may comprises connection wires which establish the electrical connection from the current source 102 to the first battery module, from the first battery module to the second battery module, etc. For example, the connection
30 arrangement 121 may comprise a plurality of connection wires, where each of them connects one terminal for the first battery module to a terminal of the second battery module. Other connection wires connect from the output terminals of the current source to the terminals of the first battery module. In this example, the power bus 125 comprises the connection wires arranged between the battery
35 modules and the current source.

In another example, the battery modules 103 are arranged to be detachably connected with the connection arrangement 121 via the battery module terminals 122. For example, the connection arrangement 121 may comprise an electrical
5 rail system to which the battery module terminals are connectable.

Individually controllable switches 104 are provided in the electrical connection between the current source 102 and the battery cells 105 in order to disconnect/
connect the battery cells 105 from/to the current source 102 or the load unit 190.
10

The load 190 may be any electrical consumer of a battery powered apparatus such as floor cleaning device. The load 190 may be connected/disconnected from the battery system 100 via an optional switch 191. For example, the load 190 may comprise electric motors, pumps, etc. of the battery powered apparatus.
15

The battery system 100 may comprise a communication bus 181 configured according to standards such CAN, I2C, SPI, RS232 or other. The communication bus connects the current source 102 and the battery modules to enable transmission of control signals, such as the current control signal 151, and other
20 signals such as battery event signals.

The communication bus 181 may further comprise a battery mode control function 182 arranged to activate the battery modules from a powered down mode where switches 104 are open to a powered mode where switches 104 are closed. The
25 battery mode control function 182 or other control function of the communication bus 181, may further be arranged to control the optional switch 191 to open when a charging process is initiated, and to close when the load 190 of the battery powered apparatus is to be powered by the battery modules. As shown in figs. 1A and 1B by dashed lines, the communication bus 181 may be arranged to be in
30 communication with the load 190.

The individually controllable switches 104 may be comprised by the battery modules 103 so that each battery module comprises a controllable switch 104. Alternatively, the switches 104 may be externally located switches, i.e. arranged
35 in series with the electrical connection between each battery module 103 and the

current source 102 to individually connect/disconnect the battery modules to/from the current source 102.

Due to the parallel connected battery modules 103, the battery modules which are
5 connected via switches 104 can be charged or discharged in parallel.

Each of the battery modules comprises at least one battery cell such as Nickel-cadmium battery cells, Lithium-ion battery cells, nickel metal hydride battery cells. The battery cells may be series connected to establish a sufficiently high
10 voltage.

The battery modules may be configured with active or passive balancing such as a balancing circuit (not shown), which can be switched in, in parallel with each battery cell, when the battery cell reaches a fully charged level such as a pre-
15 determined voltage level or charge status. The purpose of the balancing circuit is to keep the individual battery cells in balance.

Each of the battery module comprises a slave control unit 106 configured to monitor a battery condition of the battery module. Examples of battery conditions
20 includes cell voltages of individual battery cells 105, battery module voltages across all battery cells of a battery module, module charging currents flowing into individual battery modules 103, battery module capacities and temperatures of the modules under charge and discharge.

25 Both the slave control unit 106 and the master controller 101 may be configured to control the switches 104.

The slave control unit 106 is further arranged to determine battery events based on the battery condition.

30

Battery events comprises voltage events of the battery cells which are generated by the slave control unit 106 when individual cell voltages reach a voltage threshold, V_{max} , which is reached when the cell is considered fully charged. When all battery cells 105 of a battery module 103 have reached V_{max} , the battery
35 module is considered fully charged, and a "Fully Charged" battery event Mchar is

generated. The fully charged condition may further be conditioned in that the charge current to the module is below a predetermined level. A battery module may be considered fully charged in other situations, as described in connection with Fig. 3, where a "Fully Charged" battery event is similarly generated. Thus, 5 such battery events may be used to signal that a battery cell 105 and/or a battery module 103 is fully charged.

Other battery events may be generated dependent on battery module temperatures. As shown in Fig. 2A, the maximal charging current 201 of a battery 10 module 103 depends on the battery module temperature 202. For example, as illustrated, maximal charging currents I1, I2 and I3 apply for temperatures in the temperature intervals T1-T2, T2-T3 and T3-T4, respectively. Accordingly, a battery event may be generated when the temperature is within the ranges T1-T2 and T3-T4, in order to set a maximal charging current according to the 15 temperature, or to disconnect the battery module from the power bus 125 if the temperature is outside the allowed temperature range, e.g. if the temperature is above T4 or below T1.

The battery events may be determined by the slave control unit, although some 20 battery events may be determined by the master controller based on information from one or more of the slave control units.

If a slave control unit 106 detects that a temperature of its battery cells 105 are above a maximum temperature, such as 50 degrees, the slave control unit may 25 disconnect the battery module from the power bus 125 to avoid damages. The slave control unit may further send a "high-temperature" message to the master controller 101 which send switch control signals to other battery modules so as to disconnect these battery modules from the power bus.

30 Other battery events may be generated when the module charging current exceeds a maximum current, e.g. if the module charging current exceeds the maximal charging current 201 as specified for a given temperature range of the battery module temperature 202.

In general, a battery event may be generated by the slave control unit from any of the battery modules in order to generate a current control signal which controls the current source 102 to decrease the charging current. In other situations, a battery event may be generated by the master controller 101 based on
5 information from the slave control units 106.

The slave control unit 106 may be implemented as software code designed to carry out the functions of the slave control unit and to be executed by a digital processor comprised each of the battery modules 103.
10

In general, a single master controller 101 is needed by the battery system 100. Each of the battery modules 103 may be configured to establish the master controller. For example, the master controller 101 may be implemented as software code designed to carry out the functions of the master controller 101
15 unit and to be executed by a digital processor comprised each of the battery modules 103, such as the digital processor which runs the slave control unit 106.

Alternatively, the battery system 100 such as a housing of the battery system 100 may comprise a digital processor or other electronic circuit configured to embody
20 the master controller 101, e.g. via a digital processor arranged to run software code designed to carry out the functions of the master controller 101.

In case the master control unit 101 is comprised by one of the battery modules 103, the configuration of the battery module 101 to operate as the master
25 controller may be determined dependent on individual data stored by each of the battery modules 103. Such individual data may include a date, such as the production date, of the battery module 103, fault conditions stored by the module, a serial number of the battery module, the actual charging capacity, number of charge/discharge cycles and other charging data of the battery module. In this
30 way, a single battery module can always be pointed out to be responsible to carry out the master controller function.

The battery system 100 may further comprise a register 170, 170', e.g. a digital memory, which stores identification data obtained from each of the battery
35 modules. For example, the master controller 101 may be configured to store

charging data in the register 170, 170' indicating which of the battery modules has reached the fully charged battery module condition/event Mchar, a fully discharged battery module condition Mdis and other conditions such as over- and under-temperature conditions and defect conditions. A common register 170' may
5 be comprised by the battery system which is accessible for reading and writing by the master controller 103. Alternatively, one or any of the battery modules may have the register 170 implemented in a memory of the battery module.

Advantageously, if a battery module 103 is configured to implement the master controller 101, that battery module may additionally implement the register 170.

10

The battery system 100 may be configured with a communication function arranged to communicate information from the slave control units 106 to the master controller 101, such as battery event information, from the master controller 101 to the slave control units 106, such as switch control signals to
15 operate the switches 104, and from the master controller to the current source 102, such as the current control signal 151.

Fig. 2B shows a charging process where curve 211 is the voltage across the power bus 125, i.e. substantially the voltage across the series connected battery cells, and where curve 212 is the current supplied by the current source 102. The time
20 from t0 to t1 is an initial charging period where the current 212 is constant or substantially constant and where the voltage increases from an initial voltage at t0 to a maximum voltage at t1. The time from t1 to t2 is the final charging process which is described in detail in connection with Fig. 3.

25

The initial charging period may start with determining which of the battery modules 103 should be configured to operate as the master controller 101, in case two or more of the battery modules are configurable to operate as master controller.

30

The master controller may update the register 170, 170' with data from the battery modules, such as serial number or other identification data of the battery modules, the nominal capacities, defect condition data indicating if a module is defect, over- and under-temperature conditions in case any of the battery
35 modules 101 - or any of the modules which are not fully charged or defect -

satisfies such over- and under-temperature conditions (cf. Fig. 2A), and charging data indicating if a battery module is fully charge or fully discharged.

The master controller may determine that all battery modules are disconnected
5 from the power bus 125, if any of the battery modules has an over- and under-temperature condition.

The master controller may be set to a wait state, waiting for a "ready message" from the slave control unit 106 of the battery module affected by the over- and
10 under-temperature condition, so that charging can be continued when the temperature returns to the allowed temperature range.

The master controller may be configured to obtain battery module voltages from each of the battery modules or any of the modules which are not fully charged or
15 defect. The battery module voltage is the voltage measured over all battery cells of a battery module, i.e. over the core-pack 107. In order to equalize battery module voltages among the battery modules, the master controller may be configured to request that the one or more battery modules having the lowest battery module voltages or having battery module voltages below a certain
20 minimum voltage limit, to connect to the power bus 125 via the switches 104. The connection request may be in the form of a connection request signal which may include identification data of the battery modules which should connect, where the connection request signal may be transmitted via the communication bus 181.

25 The connection request may directly control the switches to connect/disconnect, or the slave control unit 106 of the relevant battery modules may control the switches dependent on the connection request.

Accordingly, the master controller may be configured to request battery modules
30 individually to connect to the power bus 125 dependent on battery module voltages obtained from one or more the battery modules.

Fig. 3 shows an example of an event-controlled charging process and how the current control signal is determined dependent on the battery event so as to

cause a reduction or increase of the charging current. The abscissa axis shows the charging time and the ordinate axis shows the charging current in amperes.

The Fig. 3 example is based on charging two battery modules 103 with a 1200
5 Watt current source 102 after the initial charging process. The current source 102 has a maximum output current, here a maximum of 36 Ampere, and is indicated by line 402. Each of the battery modules has a nominal capacity of 44800 mAh.

The first battery module 103 is named M1 and the ten battery cells of battery
10 module M1 are named M1C1 – M1C10. The second battery module 103 is named M2 and the ten battery cells of battery module M2 are named M2C1 – M2C10.

Line 403 indicates the maximal charging current 201 of each of the battery
modules M1, M2 for a normal temperature range, e.g. in the range from 10 to 40
15 degrees Celsius.

Curve 401 is the charging current supplied by the current source 102. Since the
charging current is generated in response to the current control signal, the current
control signal could be represented by curve 401, particularly when the current
20 control signal is proportional with the desired charging current.

The master controller is configured to determine the current control signal
dependent on a timer signal so that changes of the current control signal is only
possible at times given by the timer signal.

25

Curve 404 is a fully charged current level which defines when a given battery
module is considered fully charged. That is, when the charging current for a given
battery module 103 decreases below the fully charged current level 404, when the
charging current has been below the fully charged current level 404 for a period of
30 time or when a time-average of the charging current obtained over a period of
time is below the fully charged current level 404, the battery module can be
considered fully charged. The fully charged current level 404 may be determined
as a fraction of the battery module capacity, such as 1/20 of the battery capacity,
e.g. the battery capacity specified by the manufacture's datasheet.

35

In this example, the master controller 101 only determines the current control signal or changes in the current control signal at specific times, here every 100 ms. Therefore, changes in the charging current 401 is only allowed after the lapse of a certain time interval such as the 100 ms time interval. The specific times or
5 allowed times where a change of the current control signal or charging current is allowed, may include a certain tolerance time interval wherein the current control signal or the charging current is allowed to be determined, e.g. in response to a battery event. These allowed times or allowed time intervals are indicated with reference 410.

10

Accordingly, any battery event from any of the battery modules generated between the specific times, i.e. within the time intervals such as the 100 ms time intervals, may be disregarded.

15 That is, only battery events, such as only one battery event, from any of the battery modules is accepted when the event occurs at the specific times, i.e. allowed times, or within the tolerance time interval of the allowed times.

The master controller may be configured to only read the battery event when a
20 timer signal signals an allowed time. The battery event could be transmitted as a battery event signal transmitted via the communication bus 181 such as the aforementioned CAN bus and prioritized over other signals on the bus to avoid delays. Accordingly, the master controller 101 is configured to determine the current control signal dependent on the timer signal so that changes of the
25 current control signal is only possible at times given by the timer signal.

The charging current 401 at zero point of charging time, i.e. the point at the crossing between the coordinate axes, is the charging current as obtained after the initial charging process in Fig. 2B, i.e. after t_1 in Fig. 2B when charge process
30 is changed from constant current to constant voltage 211. Thus, the curve 401 represents a constant voltage phase.

A first battery event happens because the 3rd battery cell 105, M1C3 of module M1 reach the voltage threshold V_{max} because M1C3 has become fully charged.

The slave control unit 106 of battery module M1 sets the balancing resistor on the 3rd battery cell and sends the Vmax battery event, e.g. via a communication bus.

On basis of the Vmax battery event, which is received by the master controller
5 101, the master controller determines the current control signal to cause a reduction the charging current due to the reduction of the required charging current. The current control signal causes a reduction of the charging current 401.

The magnitude of the reduction or increase of the charging current 401 may be
10 determined based on predetermined rules. For example, the reduction or increase of the charging current 401 may be determined in dependence of battery module capacities of the battery modules which is currently being charged, i.e. capacities of battery modules which are not being charged, e.g. since they have reached a fully charged state, are disregarded.

15

In the example in Fig. 3, the reduction and increase is determined as predetermined percentages of the actual battery capacities, here the reduction of the charging current is given as 5% of the total actual battery capacity and the increase of charging current is 1% of the total actual battery capacity. The battery
20 module capacities may be the nominal battery module capacities or other measure of the battery module capacity. However, magnitude of the reduction or increase may be limited by to a percentage of the maximum charging current of the current source 102.

25 Thus, upon detection of a battery event, the reduction of the charging current may be the smallest of: a fifth predetermined percentage of the total battery cell capacity of the battery modules of the battery system, and a sixth predetermined percentage of the maximum charging current of the current source (102).

Similarly, upon no detection of a battery event for a predetermined amount of
30 time, such as e.g. 100 ms, the charging current is increased by the smallest of: a seventh predetermined percentage of the total battery cell capacity of the battery modules of the battery system, and an eighth predetermined percentage of the maximum charging current of the current source (102). As an example only, upon detection of a battery event, the reduction in the charging current is 5% of the
35 total actual battery capacity, but not higher than 5% of the maximum charging

capacity of the current source. As an example only, upon no detection of a battery event for e.g. 100 ms, an increase in the charging current is 1% of the battery capacity, but not higher than 1% of the maximum charging capacity of the current source.

- 5 The determined current control signal is read by the current source 102 which reduces the charging current 401 according to the current control signal. The current control signal may specify the absolute current value or a relative change. In case the current source 102 is configured to determine the charging current on basis of the battery module capacities and e.g. a predetermined percentage
10 change, the current control signal could simply indicate a desired increase or reduction of the charging current 401.

Since each of the battery modules has a nominal capacity of 44800 mAh, the charging current is reduced by 4.48 A, corresponding to 5% of the total capacity
15 of 2 x 44800 mAh.

In the Fig. 3 example, the master controller 101 generates the current control signal so as to cause an increase of the charging current automatically every 100 ms, in general after a certain time interval has lapsed, e.g. dependent on the
20 timer signal. Thus, the master controller 101 automatically sends an "increase" current instruction to the current source periodically at specific times, such as every 100 ms.

The charge current is increased by e.g. 1% of the nominal capacity of the
25 connected modules M1 and M2, equal to 0.896 Ampere, corresponding to 1% of the total capacity of 2 x 44800 mAh.

Since a reduction in the charging current may be important in order to avoid too high charging current which could damage a battery module 103, battery events
30 which would cause a reduction in the charging current may be prioritized over the aforementioned automatic increases of the charging current 401. Thus, in case the master controller 101 at the same time, e.g. at the same "allowed time", would generate both an automatic increase of the charging current and also receives a battery event for decreasing the charging current 401, the battery

event for decreasing the charging current would be prioritized over the automatic increase of the charging current.

Thus, the master controller may be configured to determine the current control
5 signal 151 so as to cause the increase of the charging current, e.g. an automatic increase of the charging current, only in the absence of any battery event for decreasing the charging current.

A second battery event happens when the M1C7 battery cell reaches V_{max} . The
10 slave control unit 106 in module 1 sets the balancing resistor on the 7th cell and the slave control unit sends a battery event signal V_{max} .

The different or distinguishable battery event signals may be generated for
different kinds of battery events, i.e. a specific and distinguishable battery event
15 may be generated by the slave control units 106 when a battery cell voltage reaches the fully charged cell-voltage V_{max} . Alternatively, the same, i.e. a common battery event signal, may be generated for different kinds of battery events. The latter alternative is feasible when different battery events should generate the same reduction of the charging current, e.g. the same percentage
20 reduction dependent on the battery capacity.

The generation of battery events due to battery cells reaching V_{max} is continued and the balancing resistors are been set on several cells in both battery modules M1 and M2.

25

A new type of a battery event is generated after all battery cells of a battery module 103 have reached the voltage threshold V_{max} . In Fig. 3, the last battery cell M1C8 of battery module 1 is fully charged at the instance indicated with letter A. Since this is the last battery cell which reaches V_{max} , a fully charged battery
30 module event Mchar is generated.

The fully charged battery module event Mchar may be generated by the slave control unit 106 of the battery module which has become fully charged, or by the master controller 103 in response to receiving a "fully charged" message from the
35 slave control unit 106.

In addition to sending the fully charged battery module event Mchar to the master controller 101, this event signal or a separate fully charged battery module message is sent and registered in the register 170 or 170' so that the register
5 170, 170' stores updated information on which of the battery modules are fully charged.

In response to registering the module M1 as fully charged, the master controller 101 may send an instruction to the battery module M1 to disconnect the power
10 terminals from the power bus 125 via switch 104. Furthermore, in response to the disconnect instruction, the slave control unit 106 may ensure that all balancing resistors are released and that battery module M1 enters a standby mode.

Since battery module 1 is disconnected, the charging current 401 is too high for
15 the remaining battery module M2. Accordingly, a reduction of the charging current 401 is needed. This may be achieved by configuring each of the slave control units 106 to monitor the battery module charging current flowing into the battery modules via the power terminals. Thus, the battery condition determined by the slave control unit of battery module M1 may indicate a too high charging current if
20 the battery module charging current is greater than a maximum current 201 specified for the battery module M1. The slave control unit of module M1 may send a battery condition indicating the too high charging current to the master controller 101, e.g. via the communication bus 181, and in response the master controller generates a maximum battery module charging current event MaxI
25 indicating that the battery module charging current exceeds the maximum current 201. Alternatively, the slave control unit of a battery module generates the maximum battery module charging current event MaxI in response to determining that the measured charging current exceeds the maximum charging current 201.

30 In response to the maximum battery module charging current event MaxI, the master controller 101 determines the current control signal 151, e.g. dependent on battery module capacities, according to methods which are equivalent with methods for determining the current control signal 151 in response to the Vmax maximum cell voltage event.

As shown at the first arrow in Fig. 3 with reference names Max. Current, the charging current 401 is decreased, e.g. by 5% of the nominal capacity of the remaining connected modules (here connected module M2), equal to 2.24 A, corresponding to 5% of the remaining total capacity of 1 x 44800 mAh.

5

However, at the next allowed time 410, the charging current 401, or the fraction of the charging current flowing into module M2 (or flowing into other modules in case two or more battery modules are still connected), is still above the maximum current. Therefore, as shown at the second arrow named "Max. Current", in

10 response to a second generated maximum battery module charging current event MaxI, the charging current 401 is reduced again.

The generation of maximum battery module charging current events MaxI is continued, here a total of four times, until the charging current flowing into

15 battery module M2 is below the maximum charging current. In Fig. 3, the maximum charging current 201 of module M2 is indicated by line 403 and it is seen that after the fourth current decrease, the charging current 401 has decreased below the maximum current level 403.

20 Now, since the slave control unit 106 of battery module M2 determines that the charging current flowing into the battery module M2 is below the maximum current 201, 403, the charging current is automatically increased at the next allowed time 410 based on the current control signal generated by the master controller 101 since no battery events for reductions in the charging current are
25 generated.

After this increase in the charging current, here a 1% increase, the maximum current 201, 403 of battery module 2 is exceeded again, and another current decrease, here a 5 % decrease, is generated in response.

30

The multiple battery events Vmax indicated with a total of five errors named M2C7 is due to an out-of-balance error where the M2C7 cell reaches the voltage threshold Vmax five times, but where the balancing resistor is set for the M2C7 cell the first time the voltage threshold Vmax is reached.

35

Similarly, battery cells M2C4 and M2C2 reaches the voltage threshold V_{max} a total of 5 times each.

The fully charged current level 404 is determined as 1/20 of the battery capacity of battery module M2. The charging current decreases below the fully charged current level 404 while battery module M2C2 continues causing generation of V_{max} battery events, while battery cells M2C1, M2C3 and M2C6 have not reached the threshold voltage V_{max} indicating a fully charged level of the cells.

10 However, since the average value of the charging current 401 during a given period, here 1000 ms, has been lower than the fully charged current level 404, module M2 is considered fully charged.

Accordingly, a second condition for considering a battery module fully charged is
15 obtained dependent on a comparison of the charging current 401, i.e. the charging current flowing into a given battery module 103, with a current threshold corresponding to the fully charged current level 404, such as a current threshold determined dependent on a battery module capacity of said battery module 103. As illustrated in the specific example, the charging current compared with the fully
20 charged current level 404 may be determined as a time-averaged charging current obtained over a given period.

Thus, the battery condition here comprises a situation where the average value of the charging current 401 or a time-average thereof has been lower than the
25 current level 404 for a given period of time. When this battery condition is fulfilled, the slave control unit 106 generates a fully charged message which is received by the master controller which generates a fully charged battery event Mchar. In response, the master controller generates a current control signal causing a reduction of the charging current similar to the previously described
30 fully charged battery event Mchar. However, if it is the last battery module of the plurality of battery modules which has become fully charged, the master controller may generate a current control signal which sets the charging current to a final low current which may be used for powering the e.g. a controller, while all battery modules are disconnected via the switches 104.

The battery capacity used for determining a fully charged condition when the charging current is below a fraction of the capacity, or used for determining the increases/decreases of the charging current may be the nominal capacity, an actual capacity which may be determined as a function of e.g.

5 charging/discharging cycles, and other measures of the battery.

It should be noted that fig. 3 shows an example of an event-controlled charging process with two battery modules, only, for reasons of simplicity. However, the concept of the event-controlled charging process is similar for battery systems

10 with any practical number of battery modules.

Fig. 4 provides an overview of some battery events. Other events include over-current during charge and discharge, short-circuit during charge and discharge, high temperature during charge, low temperature during charge, over-temperature during charge and discharge, under-temperature during charge and discharge and defect battery module.

During discharging, when one or more of the battery modules are connected to the load 190 via the closed switch 191 and one or more of switches 104. Thus, two or more battery modules may be discharged in parallel. The master controller 106 may update the register 170 or 170' during the discharging, e.g. information on the charging status such as when a battery module is fully discharged.

Fig. 5 is a flow diagram over a method 500 to determine which of the battery modules should be configured to operate as the master controller, e.g. during charging of the battery system. During step 501, 510, 511, 512 and 514, all the master controllers 101 of the battery modules 103 are active. The method 500 starts in step 501 and continues to step 510, wherein it is determined whether the battery system 100 includes a single battery module 103 or more than one battery module 103. In the case, where step 510 indicates that the battery system 100 does not include more than one battery module, the flow continues to step 511 wherein it is determined that the single battery module 103 becomes the master controller. In this case, both the master controller 101 and the slave control unit 105 of the single battery module 105 become active. Subsequently, the flow ends in step 520.

If step 510 results in the determination, that the battery system 100 comprises more than one battery module 103, the flow continues to step 512 wherein individual data from the different battery modules 103 are compared. Such individual data are e.g. a date, such as the production date, of the battery modules 103, fault conditions stored by the battery modules 103, a serial number of the battery modules 103, the actual charging capacity, number of charge/discharge cycles and other charging data of the battery module 103. For example, the decision on the battery module 103 to be master module is the battery module having the newest production date or the highest serial number. In this way, a single battery module can always be pointed out to be responsible to carry out the master controller function, in step 514. Subsequently, only the master controller of the single battery module appointed to be the battery module also responsible to carry out the master controller function is active, whilst the master controller of the remaining battery modules, if any, are passive. However, the slave control unit 106 of the battery modules 103 with a passive master controller will remain active. The method ends in step 520.

Although the present invention has been described in connection with the specified embodiments, it should not be construed as being in any way limited to the presented examples. The scope of the present invention is to be interpreted in the light of the accompanying claim set. In the context of the claims, the terms "comprising" or "comprises" do not exclude other possible elements or steps. Also, the mentioning of references such as "a" or "an" etc. should not be construed as excluding a plurality. The use of reference signs in the claims with respect to elements indicated in the figures shall also not be construed as limiting the scope of the invention. Furthermore, individual features mentioned in different claims, may possibly be advantageously combined, and the mentioning of these features in different claims does not exclude that a combination of features is not possible and advantageous.

CLAIMS

1. A battery module comprising
 - at least one battery cell (105),
 - a battery module terminal (122) arranged to detachably connect with a
 - 5 connection arrangement (121), where the connection arrangement (121) is arranged to electrically connect a plurality of the battery modules in parallel to enable parallel charging/discharging via individual switches (104),
 - a master controller (101) arranged to determine a current control signal (151) for controlling and adjusting a charging current (401) from a current source
 - 10 (102),
 - a slave control unit (106) configured to monitor a battery condition of the battery module, where the slave control unit (106) and/or the master controller (101) is arranged to determine a battery event based on the battery condition, where the master controller is configured to
 - 15 - determine the current control signal (151) dependent on the battery event so as to cause a reduction or increase of the charging current, and to determine the current control signal dependent on battery module capacities of the one or more battery modules being connected to the current source via the individual switches (104).
 - 20
2. A battery module according to claim 1, wherein a magnitude of the reduction or the increase of the charging current is determined dependent on the battery module capacities of said one or more battery modules.
- 25 3. A battery module according to any of the preceding claims, wherein the master controller is configured to determine the current control signal so as to cause an increase of the charging current only in the absence of the battery event.
4. A battery module according to any of the preceding claims, where the master
- 30 controller is configured to determine current control signal dependent on a timer signal so that changes of the current control signal is only possible at times given by the timer signal.
5. A battery module according to any of the preceding claims, where the slave
- 35 controller is configured to determine a fully charged condition (Mchar) of one of

the battery modules dependent on a comparison of the charging current with a current threshold or to determine the fully charged condition when all cell voltages of the battery module has reached a maximum voltage.

5 6. A battery module according to any of the preceding claims, where the battery module comprises one of the switches.

7. A battery module according to any of the preceding claims, wherein the switch
10 source or a load.

8. A battery module according to any of the preceding claims, wherein upon detection of a battery event, the reduction of the charging current: a first predetermined percentage of the total battery cell capacity of the battery module
15 (103), or a second predetermined percentage of the maximum charging current of the current source (102); whichever reduction is the smallest.

9. A battery module according to any of the preceding claims, wherein upon no detection of a battery event for a predetermined amount of time, the increase of
20 the charging current is: a third predetermined percentage of the total battery cell capacity of the battery module (103), or a fourth predetermined percentage of the maximum charging current of the current source (102); whichever increase is the smallest.

25 10. A battery system (100) comprising
- a master controller (101) arranged to determine a current control signal for controlling and adjusting a charging current from a current source (102),
- one or more battery modules (103) comprising battery module terminals (122),
- a connection arrangement (121) arranged to electrically connect the one or
30 more battery modules (103) in parallel via the battery module terminals (122) to enable parallel charging/discharging via individual switches (104), where each battery module comprises
- at least one battery cell (105),
- a slave control unit (106) configured to monitor a battery condition of the
35 battery module, where the slave control unit (106) and/or the master controller

(101) is arranged to determine a battery event based on the battery condition, and where the master controller is configured to

- determine the current control signal dependent on the battery event from any of the battery modules so as to cause a reduction or increase of the charging
- 5 current, and to determine the current control signal dependent on battery module capacities of the one or more battery modules being connected to the current source or via the individual switches (104).

11. A battery system (100) according to claim 10, wherein each of the battery
10 modules comprises a digital processor which is configurable to operate as the master controller.

12. A battery system (100) according to any of claims 10 or 11, wherein the configuration to operate as the master controller is determined dependent on
15 individual data stored by each of the battery modules

13. A battery system (100) according to any of claims 10 to 12, wherein the battery system comprises a register which stores identification data obtained from each of the battery modules and wherein the master controller is configured to
20 store charging data in the register indicating a fully charged and/or discharge condition of the battery modules.

14. A battery system (100) according to any of claims 10 to 13, wherein the battery system comprises a communication function (181) arranged to
25 communicate information, such as the battery event, from the slave control unit (106) to the master controller (101) and to communicate the current control signal (151) to the current source.

15. A battery system (100) according to any of claims 10 to 14, wherein the
30 master controller is configured to request battery modules individually to connect to the current source (102) dependent on battery module voltages obtained from the one or more battery modules, where the battery module voltage is a voltage over the series connected battery cells (105).

16. A battery system (100) according to any of the claims 10 to 15, wherein upon detection of a battery event, the reduction of the charging current is: a fifth predetermined percentage of the total battery cell capacity of the battery modules (103) of the battery system (100), and a sixth predetermined percentage of the maximum charging current of the current source (102); whichever reduction is the smallest.

17. A battery system (100) according to any of the claims 10 to 16, wherein upon no detection of a battery event for a predetermined amount of time, the charging current is increased: a seventh predetermined percentage of the total battery cell capacity of the battery modules (103) of the battery system (100), and an eighth predetermined percentage of the maximum charging current of the current source (102); whichever increase is the smallest.

18. A battery powered apparatus comprising the battery system (100) of any of the claims 10 to 17 and a load (190), where the apparatus is arranged to be powered by the battery system.

19. A battery-charger system (180) comprising the battery system (100) of claim 10 to 17 and the current source (102).

20. A method for determining which of the battery modules (103) should be configured to operate as the master controller (101), comprising:
- if the battery system comprises a single battery module (103), the single battery module is to operate as the master controller (101);
- if the battery system comprises more than one battery module (103), individual data stored by each of the battery modules (103) is used to determine which battery module is to operate as the master controller.

21. A method for charging a battery system, where the battery system comprises
- a master controller arranged to determine a current control signal for controlling and adjusting a charging current from a current source,
- one or more battery modules comprising battery module terminals,
- a connection arrangement arranged to electrically connect the one or more battery modules in parallel via the battery module terminals to enable parallel

charging/discharging via individual switches, where each battery module comprises

- at least one battery cell,
 - a slave control unit configured to monitor a battery condition of the
- 5 battery module and to determine a battery event based on the battery condition, where the method comprises:
- determining the current control signal dependent on the battery event from any of the battery modules so as to cause a reduction or increase of the charging current, and
- 10 - determining the current control signal dependent on battery module capacities of the one or more battery modules being connected to the current source or via the individual switches.

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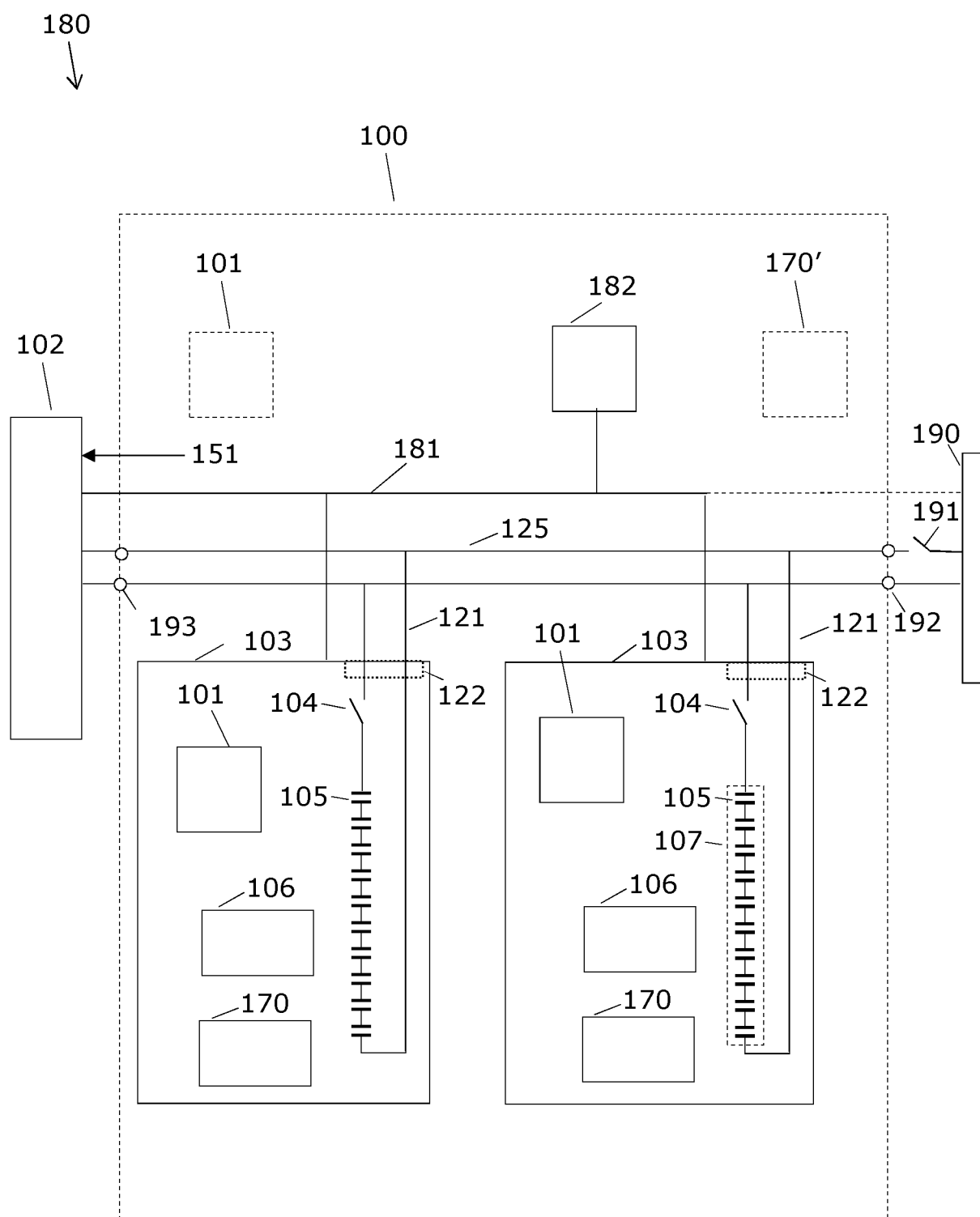


Fig. 1A

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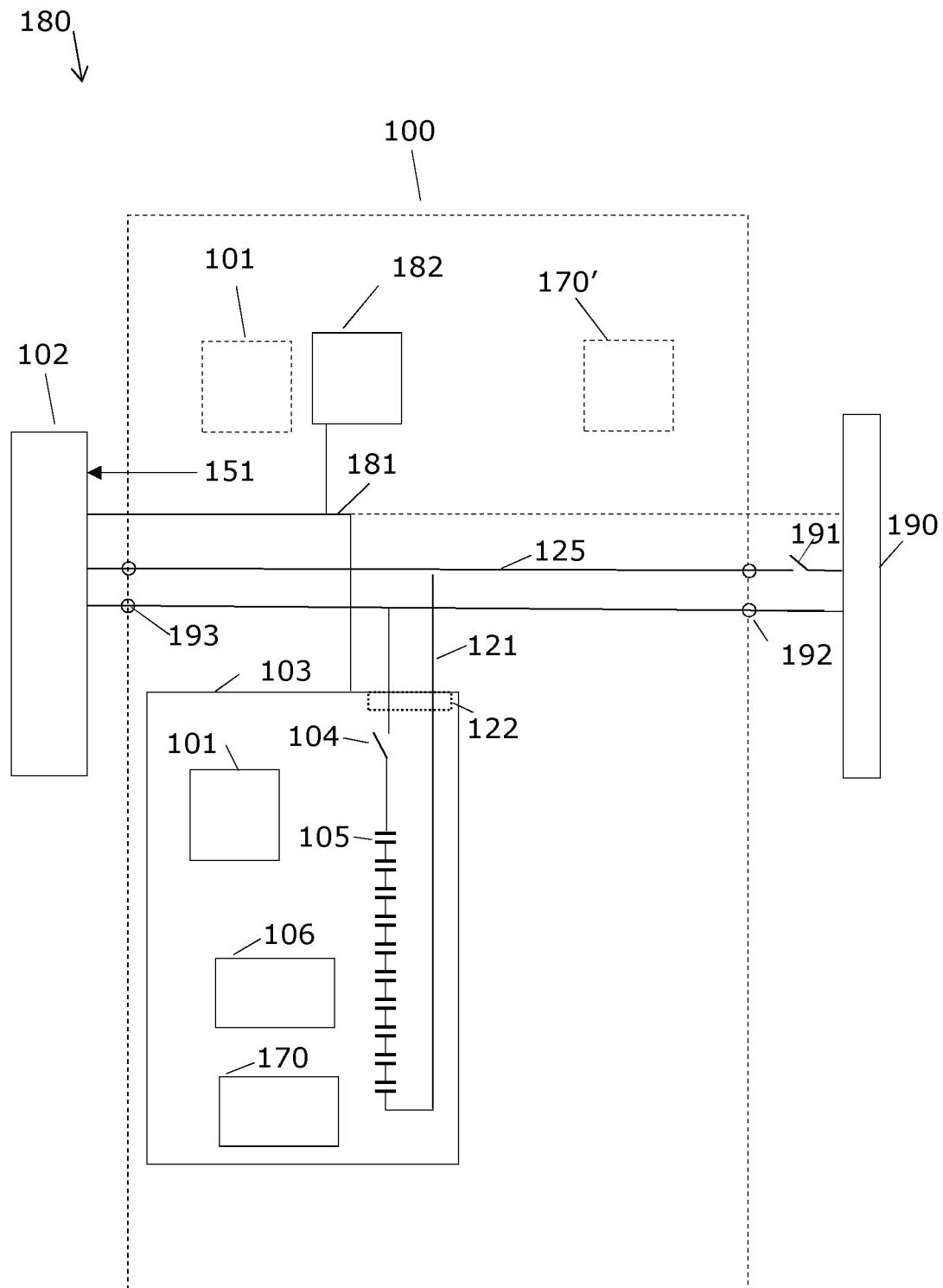


Fig. 1B

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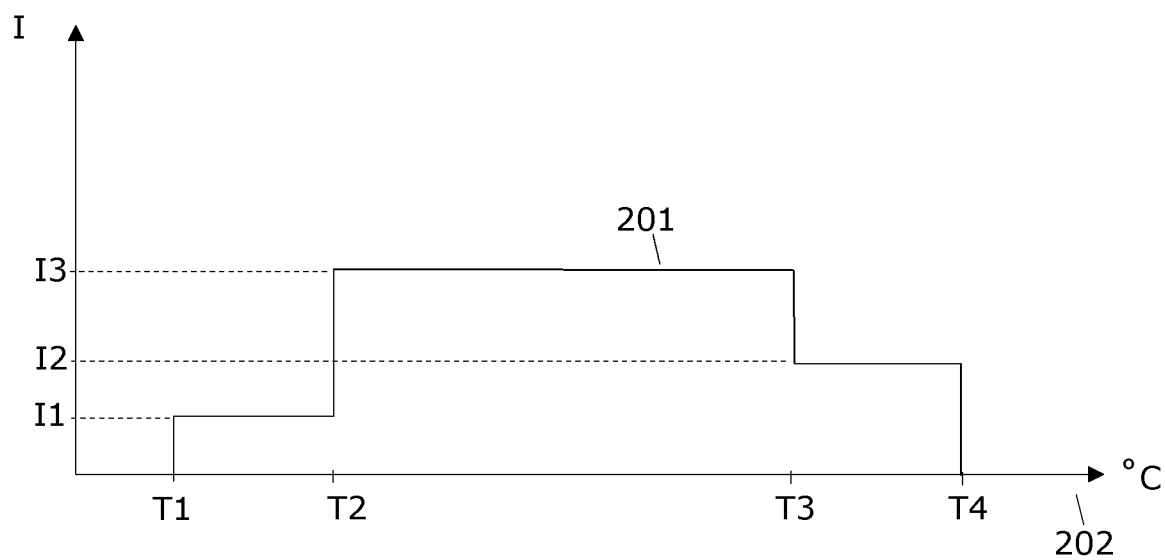


Fig. 2A

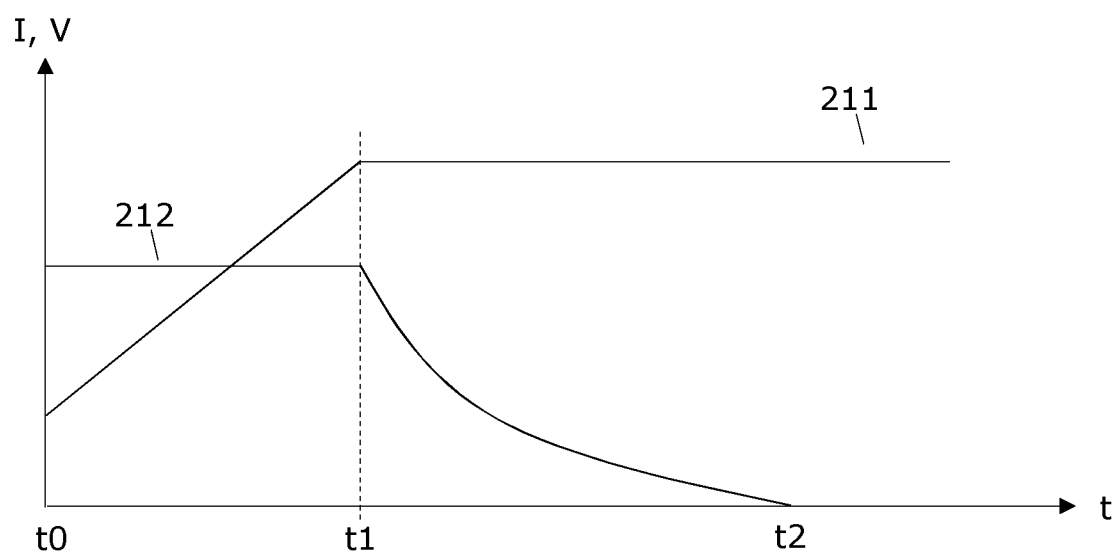


Fig. 2B

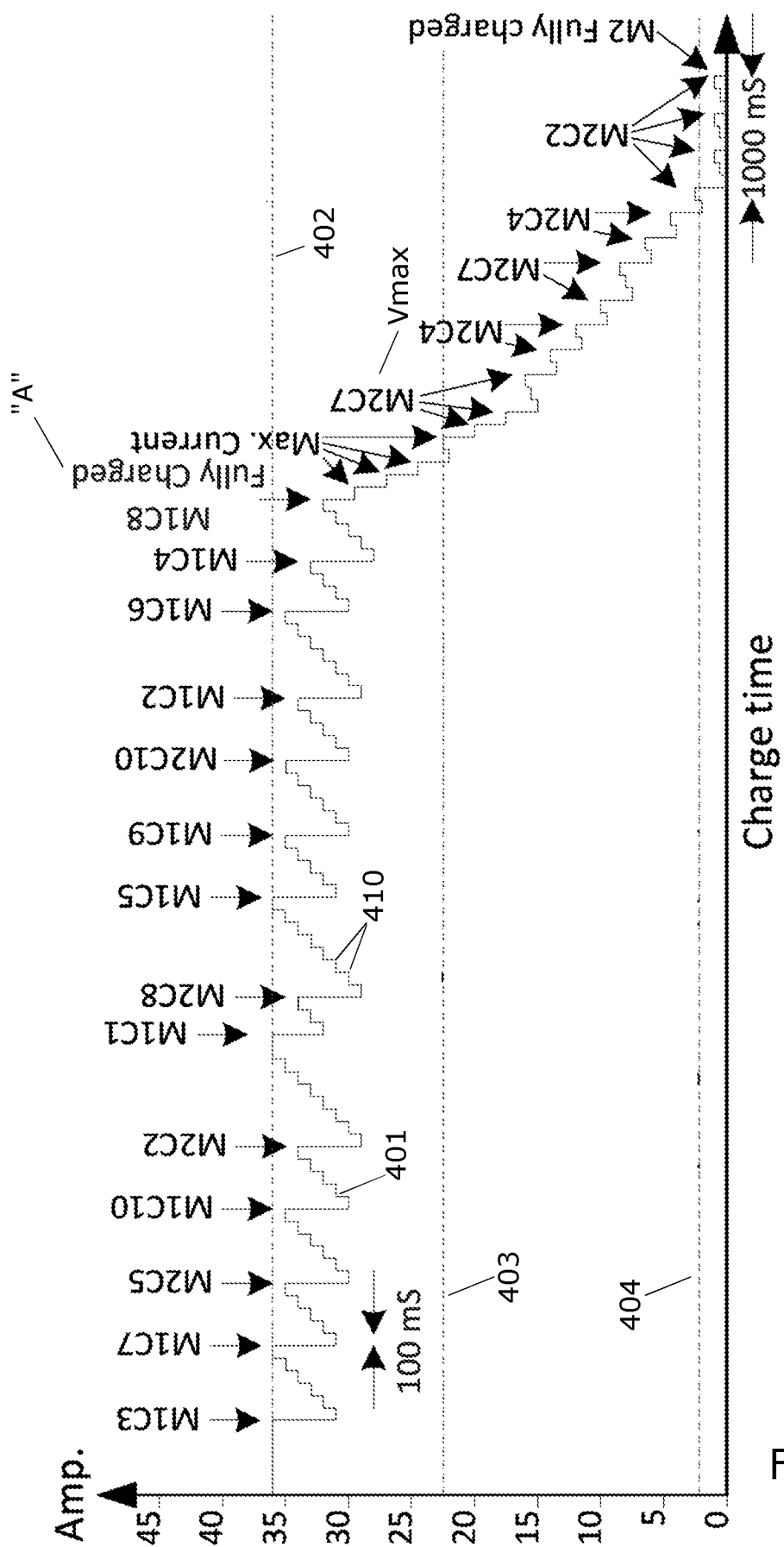


Fig. 3

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Signal name	Type	Explanation
Vmax	Battery event	Voltage threshold indicating that a battery shell has reached a voltage where it is considered fully charged
Mchar	Battery event	A battery module has become fully charged
Mdis	Battery event	A battery module has become fully discharged
MaxI	Battery event	A measured charging current exceeds the maximum charging current 201

Fig. 4

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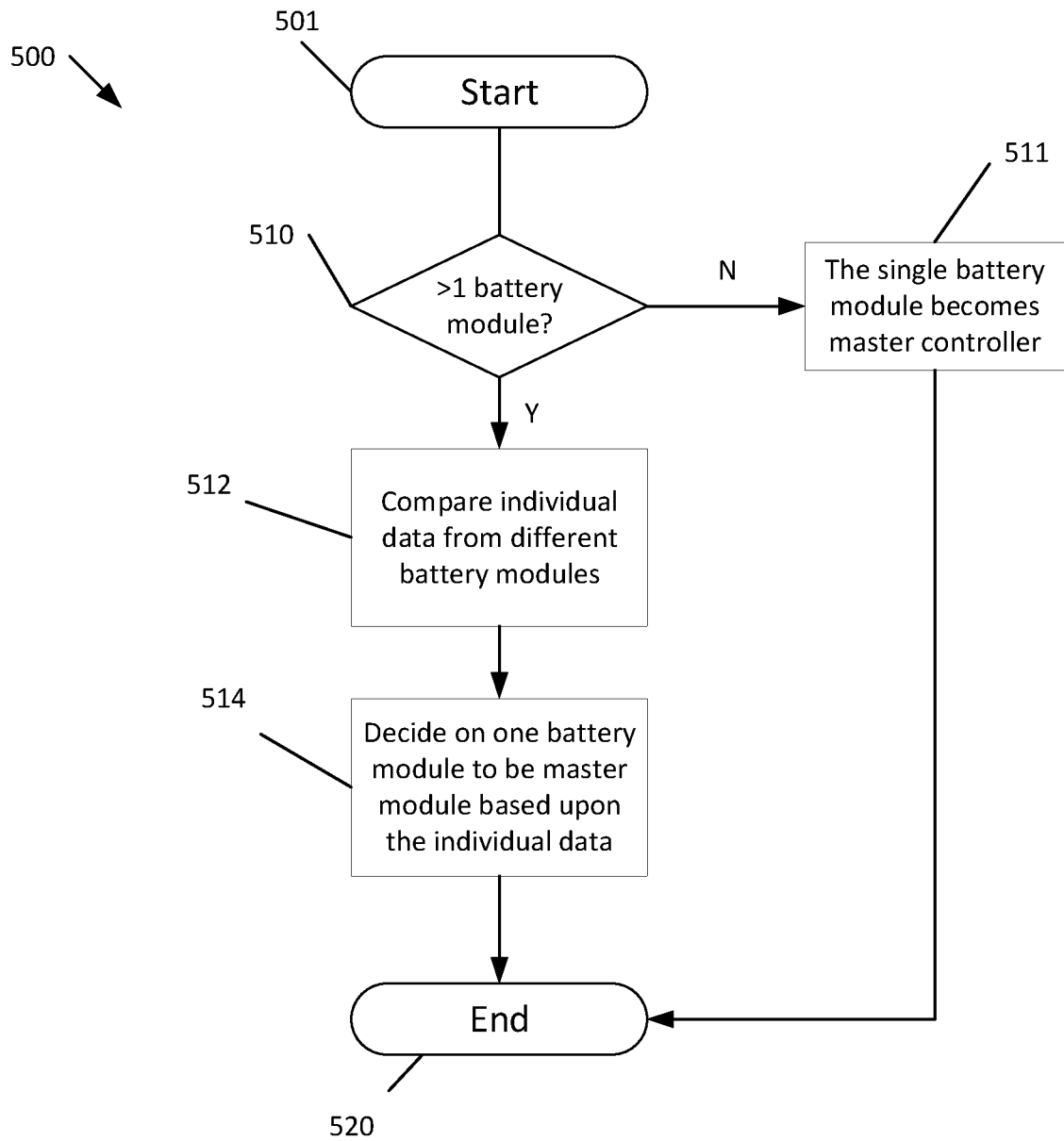


Fig. 5

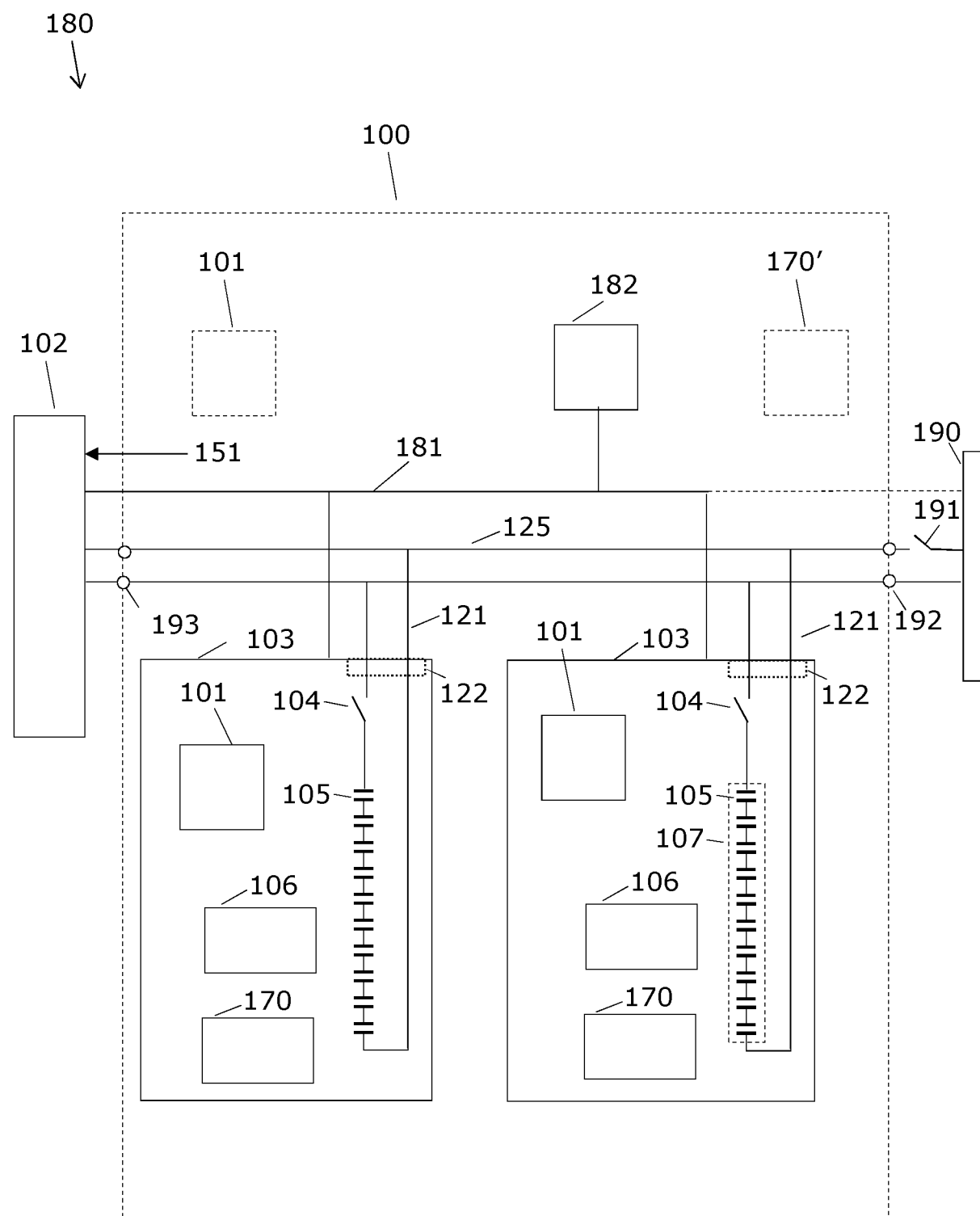


Fig. 1A