

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
18 May 2006 (18.05.2006)

PCT

(10) International Publication Number
WO 2006/052044 A1

(51) International Patent Classification: ⁷ **H01M 10/44**

(21) International Application Number:
PCT/KR2004/003104

(22) International Filing Date:
29 November 2004 (29.11.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/985,703 11 November 2004 (11.11.2004) US

(71) Applicant: **LG CHEM, LTD.** [KR/KR]; LG Twin Tower,
20, Yoido-dong, Youngdungpo-gu, Seoul 150-721 (KR).

(72) Inventor: **PLETT, GREGORY L.**; 4660, Squirreltail
Drive, Colorado Springs, Colorado 80920 (US).

(74) Agent: **KIM, Seong-Ki**; 14F., Kukdong Building, 60-1,
Chungmuro3-ka, Chung-ku, Seoul 100-705 (KR).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,

AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN,
CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI,
GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE,
KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD,
MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG,
PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM,
TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM,
ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),
European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI,
FR, GB, GR, HU, IE, IS, IT, LU, MC, NL, PL, PT, RO, SE,
SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:

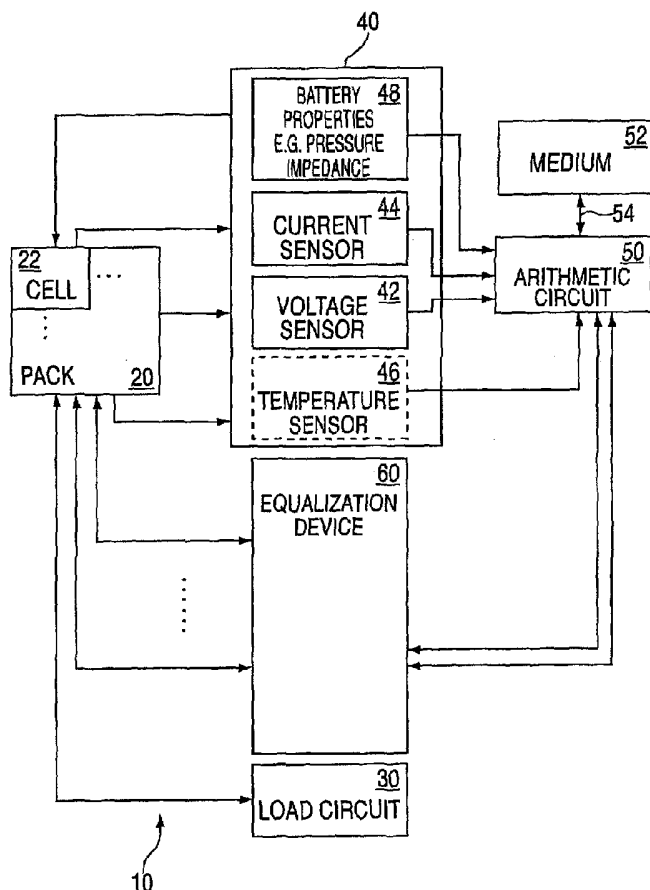
— as to non-prejudicial disclosures or exceptions to lack of
novelty (Rule 4.17(v))

Published:

— with international search report

[Continued on next page]

(54) Title: METHOD AND SYSTEM FOR CELL EQUALIZATION USING STATE OF CHARGE



(57) Abstract: The present invention relates to an implementation of a method for cell equalization. The present invention uses other information such as the individual cell state-of-charge (SOC) estimates, and individual capacities and/or cell Coulombic efficiencies, possibly available from a dual extended Kalman filter. The present invention defines or refers to an operational SOC range between a minimum and a maximum. The minimum and maximum could be constants or could be dynamic based on functions of other variables. SOC can be measured relative to maximum charge or relative to maximum discharge for each cell. When the SOC is not consistent across the cells, a prioritizing scheme is used to determine which cells require equalization.

WO 2006/052044 A1



— with a declaration as to non-prejudicial disclosures or exceptions to lack of novelty

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Description

METHOD AND SYSTEM FOR CELL EQUALIZATION USING STATE OF CHARGE

[1]

Technical Field

[2] The present invention relates generally to cell equalization using state-of-charge (SOC) and, in particular, to cell equalization in a multi-cell battery pack.

Background Art

[3] Batteries are used in a wide variety of electronic and electrical devices. In the context of rechargeable battery pack technologies with multiple cells, it is often desirable to balance or equalize the cells in the battery pack. For example, it is desirable to balance or equalize cells that are configured in series strings. Cells are configured in series strings in order for battery packs to achieve high power levels with a reasonable current source/drain. The higher voltage of a series string allows a lower current for the same power level. Generally, in the prior art, the terms 'balancing' and 'equalizing' refer to the process of causing a terminal voltage of all the cells to converge to a constant level.

[4] Over time, a battery pack's cells may become 'out of balance' as small differences in their individual dynamics-principally, in their Coulombic efficiencies and capacities-cause their states-of-charge to drift apart from each other as the pack operates. Unfortunately, one or more cells may eventually limit the discharge ability of the pack by having state-of-charge (SOC) much lower than that of the others, and/or one or more cells may limit the charging capacity of the pack by having SOC much higher than that of the others. In an extreme case, the pack becomes incapable of either charge or discharge if one cell is at the low SOC limit and another is at the high SOC limit, even if all other cells have intermediate SOC values. Packs may be balanced or equalized by 'boosting' (individually adding charge to) cells with SOC too low, 'bucking' or 'shunting' (individually depleting charge from) cells with SOC too high or 'shuffling' (moving charge from one cell to another).

[5] In some applications, for example, those with long discharge periods followed by a complete charge, equalization is only performed at the end-of-charge point in a charging process and continues until the pack is fully balanced. Other applications, however, require that the pack undergo continuous partial-charge and partial-discharge periods, and so equalization needs to be performed as the pack operates where cells in

the battery pack have their charge levels adjusted continuously in a direction leading toward a fully balanced pack. Equalization may be halted if cells become close enough to full balance for the problem at hand, and may be resumed if the cells become significantly out of balance again.

- [6] In the prior art, determining which cells should have their charge levels adjusted to equalize the pack is generally done on the basis of cell voltage alone. If all cell voltages are the same, perhaps within some tolerance, the pack is considered properly balanced. If a cell's voltage is too high, then charge needs to be depleted from the cell. If a cell's voltage is too low, then charge needs to be added to the cell. Various electronic means are available to perform the equalization, either automatically, or under microprocessor control. These include: shuffling charge, depleting charge, and adding charge. For shuffling charge, charge is moved from one or more cells with voltage too high to one or more cells with voltage too low. A switched capacitor may be used or an energy-transfer method based on transformer windings may be used. For depleting charge, charge is depleted from one or more cells with voltage too high (e.g., with a switched resistor). For adding charge, charge is added from an external source, or from the pack itself (e.g., with a DC-DC converter). A disadvantage of using cell voltage as an indicator of when to perform equalization, as well as to control the cell equalization, is that it fails to maximize performance of the battery pack.

- [7] The purpose of equalization is to maintain the battery pack in a state where the maximum level of charge and discharge power is available for use. There is a need for a method of improving performance of a battery pack by boosting or bucking or shuffling charge among cells to maximize the pack availability.

Description of Drawings

- [8] These and other features, aspects and advantages of the present invention will become better understood with regard to the following description, appended claims and accompanying drawings wherein like element are numbered alike:
- [9] Figure 1 depicts an exemplary system for cell equalization in accordance with an exemplary embodiment;
- [10] Figure 2 is a flow diagram illustrating an exemplary methodology in accordance with an exemplary embodiment of the present invention; and
- [11] Figure 3 is a flow diagram illustrating another exemplary methodology, in accordance with an exemplary embodiment of the present invention.

Disclosure

- [12] To meet these needs and address these problems, various embodiments of methods

and apparatus for cell equalization are disclosed. For example, disclosed in one exemplary embodiment is a method for cell equalization in battery packs, comprising: determining a state-of-charge for each cell of a plurality of cells; prioritizing the plurality of cells according to state-of-charge; and equalizing the plurality of cells according to the prioritizing.

- [13] In another exemplary embodiment there is disclosed a method for cell equalization in battery packs, comprising: determining a state-of-charge for each cell of a plurality of cells; determining at least one of a charge capacity and a discharge capacity for each cell of the plurality of cells; and equalizing one or more cells of the plurality of cells, when at least one of; a charge capacity of at least one cell of the plurality of cells is lower than a charge capacity of an other cell of the plurality of cells by a selected threshold, and a discharge capacity of at least one cell of the plurality of cells is lower than a discharge capacity of an other cell of the plurality of cells by a selected threshold.
- [14] Disclosed herein in another exemplary embodiment is system for cell equalization in battery packs, comprising: a battery pack with a plurality of cells; a sensor in operable communication with at least two cells of the plurality of cells configured to facilitate determination of state of charge for each cell of the at least two cells; and a controller in operable communication with the sensor and the plurality of cells. The controller is configured to to equalize charge of a cell of the at least two cells of the plurality of cells based on a state-of-charge for each cell of the plurality of cells.
- [15] Also disclosed herein in an exemplary embodiment is system for cell equalization in battery packs, comprising: a means for determining a state-of-charge for each cell of a plurality of cells; a means for determining at least one of a charge capacity and a discharge capacity for each cell of the plurality of cells; and a means for equalizing one or more cells of the plurality of cells, when at least one of; a charge capacity of at least one cell of the plurality of cells is lower than a charge capacity of an other cell of the plurality of cells by a selected threshold, and a discharge capacity of at least one cell of the plurality of cells is lower than a discharge capacity of an other cell of the plurality of cells by a selected threshold.
- [16] Disclosed herein in yet another exemplary embodiment is a storage medium encoded with a machine-readable computer program code, wherein the storage medium includes instructions for causing a computer to implement a method for cell equalization in battery packs.
- [17] Further, in another exemplary embodiment there is disclosed a computer data

signal embodied in a computer readable medium the computer data signal comprising code configured to cause a computer to implement a method for cell equalization in battery packs

Mode for Invention

- [18] Disclosed herein in one or more exemplary embodiments is a methodology and system for cell equalization using state of charge (SOC). In particular, by employing additional information such as the individual cell SOC estimates, and possibly individual capacities and/or cell Coulombic efficiencies, beyond cell voltage, equalization of a plurality of cells is possible. In another exemplary embodiments SOC computed based on standard, or dual Kalman filtering or a standard, or dual extended Kalman filter, equalizing cell voltage is further enhanced to maximize battery pack level of charge and discharge power.
- [19] FIG. 1 shows the components of a cell equalization system 10 according an embodiment of the present invention. Electrochemical cell pack 20 comprising a plurality of cells 22, e.g., battery is connected to a load circuit 30. For example, load circuit 30 could be a motor in an Electric Vehicle (EV) or a Hybrid Electric Vehicle (HEV). An apparatus for measuring state of charge is provided as 40. The SOC measurement apparatus 40 may include but not be limited to a device for measurement of cell terminal voltage are made with a voltage sensor 42, e.g., voltmeter and the like, while measurements of cell current are made with a current sensing device 44, e.g., an ammeter and the like. Optionally, measurements of cell temperature are made with a temperature sensor 46, e.g., thermometer and the like. Pressure sensors and/or impedance sensors 48 are also possible and may be employed for selected types of cells. Various sensors may be employed as needed to evaluate the characteristics and properties of the cell(s). Voltage, current, and optionally temperature and measurements of other cell properties measurements are processed with an arithmetic circuit 50, e.g., processor or computer, which estimates the states and parameters of the cell. That may include or command the equalization device 60 configured to manipulate the charge of each cell 22 of the pack 20. The system may also include a storage medium 52 comprising any computer usable storage medium known to one of ordinary skill in the art. The storage medium is in operable communication with arithmetic circuit 50 employing various means, including, but not limited to a propagated signal 54.
- [20] In order to perform the prescribed functions and desired processing, as well as the computations therefore (e.g., the equalization of cells prescribed herein, and the like),

arithmetic circuit 50 may include, but not be limited to, a processor(s), gate array(s), custom logic, computer(s), memory, storage, register(s), timing, interrupt(s), communication interfaces, and input/output signal interfaces, as well as combinations comprising at least one of the foregoing. Arithmetic circuit 50 may also include inputs and input signal filtering and the like, to enable accurate sampling and conversion or acquisitions of signals from communications interfaces and inputs. Additional features of arithmetic circuit 30 and certain processes therein are thoroughly discussed at a later point herein.

[21] One or more embodiments of the invention may be implemented as new or updated firmware and software executed in arithmetic circuit 50 and/or other processing controllers. Software functions include, but are not limited to firmware and may be implemented in hardware, software, or a combination thereof. Thus a distinct advantage of the present invention is that it may be implemented for use with existing and/or new processing systems for electrochemical cell charging and control.

[22] A methodology for cell equalization is illustrated in Figure 2. In an exemplary embodiment, the cells to equalize are determined in order to maximize the available power from a battery pack. In an exemplary embodiment, SOC is determined for the cells of a battery pack and the cells are ranked according to their respective SOC. An equalization process is applied to the cells based on this ranking. At step 101, the SOC is determined for each cell and may be an ongoing process, in some embodiments. After SOC is determined, the cells are ranked at step 102 based on their individual SOCs. At step 103, an equalization process is applied to the cells based on this ranking. For example, the equalization could be performed by adding or deleting charge, charge shuffling, or any other energy transformation scheme suitable. The decision to proceed with equalization is based on SOC, not on voltage levels as in the prior art. In addition, the sufficiency of the equalization process is determined by SOC measurements.

[23] If error bounds on the SOC estimate are available, they may be used to determine when to stop equalization. One example is if some form of Kalman filtering (e.g., an extended Kalman filter) is used to estimate SOC, then the error bounds may be computed as a function of the SOC estimation error covariance. In an example implementation, one might turn off equalization if the difference between maximum and minimum SOC falls within a function of the SOC error bounds.

[24] In addition, if the same cell is targeted for both boosting and bucking, it is the cell limiting performance whether or not its SOC is changed, so equalization may be turned

off.

[25] Figure 3 is a flow diagram illustrating another exemplary method. In implementing embodiments of the present invention on a pack of cells, assume that the pack comprises k cells (or modules of parallel-connected cells) connected in series. At step 201, the SOC of each of these cells (or modules) is determined by known means and is denoted by $z_k(t)$, where t indicates time.

[26] There are a number of existing methods for estimating the state of a charge of a cell. SOC is a value, typically reported in percent, which indicates the fraction of the cell capacity presently available to do work. A number of different approaches to estimating SOC have been employed: a discharge test, ampere-hour counting (Coulomb counting), measuring the electrolyte, open-circuit voltage measurement, linear and nonlinear circuit modeling, impedance spectroscopy, measurement of internal resistance, coup de fouet, and some forms of Kalman filtering. Each of these methodologies exhibits advantages as well as limitations.

[27] Another method for determination of SOC is disclosed in commonly assigned U. S. Patent 6,534,954 to Plett, the contents of which are incorporated by reference herein in their entirety. Similarly, SOC may be calculated as disclosed in commonly assigned U. S. Patent Application No. XX/XXX,XXX, Assignee Docket No. CPI-8, Attorney Docket No. LGC-0006 Filed on TBD also by Plett, the contents of which are incorporated by reference herein in their entirety. In these examples, a filter, preferably a Kalman filter is used to estimate SOC by employing a known mathematical model of cell dynamics and measurements of cell voltage, current, and temperature. Advantageously, these methods directly estimate state values for the cell where SOC is at least one of the states. Moreover, these methodologies enhance the equalization methodologies of the exemplary embodiments disclosed herein by facilitating establishing termination conditions for the equalization of cells. It will be appreciated that there are numerous well-known methodologies for computing SOC.

[28] In one exemplary embodiment, there are operational design limits established such that SOC $z_k(t)$ is maintained within in the range $z_{\min} \leq z_k \leq (t) z_{\max}$, where $z_{\min}$ and $z_{\max}$ might be constants, or might be functions of other variables (such as temperature). Further, in cases where no other limits are applied, then we may consider $z_{\min} = 0\%$ and $z_{\max} = 100\%$.

[29] Continuing with Figure 2, at step 202, for SOC of each cell k at level $z_k(t)$, the quantity of charge that can be accepted by this cell in ampere-hours from an upper limit, denoted present charge capacity, or the quantity of charge that can be depleted

this cell to a lower limit, denoted present discharge capacity. The upper limit distance (present charge capacity) is represented as:

$$[30] \quad C_k^{\text{charge}}(t) = (z_{\text{max}} - z_k(t))C_k / \eta_k, (1)$$

[31] and the distance in ampere-hours from the lower limit (present discharge capacity) is:

$$[32] \quad C_k^{\text{discharge}}(t) = (z_k(t) - z_{\text{min}})C_k, (2)$$

[33] where C_k is the capacity of cell k , in ampere-hours and η_k is the Coulombic efficiency of cell k . If all cells exhibit substantially equivalent present charge capacity, $C_k^{\text{charge}}(t)$, (or within some threshold range of each other, e.g. within 5%), at step 203, then no cell will limit pack charge capacity and no equalizing is needed as indicated at step 204. Similarly, if all cells have equal $C_k^{\text{discharge}}(t)$, (or within the threshold range) then no cell will limit pack discharge capacity and no equalizing is required at step 204. Note that embodiments of the present invention may be practiced using either charge distance or discharge distance (or both) without departing from the scope of the invention.

[34] However, if the capacity $C_k^{\text{charge}}(t)$ of at least one cell is lower than that of others by, for example, the threshold amount, this cell will limit the ability of the pack to accept charge and therefore, equalization is desired. Similarly, if the capacity $C_k^{\text{discharge}}(t)$ of one cell is lower than the others (or outside the acceptable threshold range of similarity), this cell will limit the ability of the pack to supply charge to a load and equalization should be performed.

[35] If equalization is desired, the 'distance' information is used to determine which cells require equalization at step 205 and equalization is applied at step 206, according to the following exemplary methodology.

[36] 1. Compute $C_k^{\text{discharge}}(t)$ for all cells, and sort from smallest to largest. The cells with smallest value may benefit from having some charge depleted (via bucking, charge shuffling, or energy transformation) prioritized in reverse order by the magnitude of its $C_k^{\text{discharge}}(t)$.

[37]

[38] 2. Compute $C_k^{\text{charge}}(t)$ for all cells, and sort from smallest to largest. The cells with smallest value may benefit from having charge added (via boosting, charge shuffling, or energy transformation) prioritized in reverse order by the magnitude of its $C_k^{\text{charge}}(t)$.

[39] 3. If charge shuffling is available, it is shuffled from the cells with minimum $C_k^{\text{charge}}(t)$ to cells with minimum $C_k^{\text{discharge}}(t)$, prioritized in reverse order by the cor-

responding magnitudes.

- [40] If error bounds on the SOC estimate are available, they may be used to determine when to stop equalization. For example, if some form of Kalman filtering (e.g., a Kalman filter, an extended Kalman filter, and the like) is used to estimate SOC, then the error bounds may be computed as a function of the SOC estimation error covariance. In an example implementation, equalization may be terminated if the difference between maximum and minimum $C_k^{\text{discharge}}(t)$ and the difference between maximum and minimum $C_k^{\text{charge}}(t)$ falls within a function of the SOC error bounds. In addition, if the same cell is targeted for both boosting and bucking, it is the cell limiting performance whether or not its SOC is changed, so equalization may be terminated.

- [41] If cell capacity information is not individually available, then the nominal capacity C_n may be used. If cell Coulombic efficiency information is not individually available, then the nominal efficiency η_k may be used. If so, the procedure then equalizes SOC.

Industrial Applicability

- [42] In summary, various embodiments are disclosed of ways of determining which cells in a battery pack having a series-connected string of cells or modules are be equalized. Some embodiments do not simply equalize cell voltage, but also maximize the pack availability. Some embodiments incorporate knowledge, if available, of individual cell capacities and Coulombic efficiencies. As cells in a battery pack age, their characteristics will not remain equal, so using the disclosed embodiments the pack provides better performance in the long run. Various embodiments include methods to equalize a series string of cells on a continuous basis. An example context is a battery system in a Hybrid Electric Vehicle (HEV). Note that the invention is not limited to vehicular applications, however, but may be applicable to any situation where cell equalization is desired.

- [43] The disclosed method may be embodied in the form of computer-implemented processes and apparatuses for practicing those processes. The method can also be embodied in the form of computer program code containing instructions embodied in tangible media 52, such as floppy diskettes, CD-ROMs, hard drives, or any other computer-readable storage medium, wherein, when the computer program code is loaded into and executed by a computer, the computer becomes an apparatus capable of executing the method. The present method can also be embodied in the form of computer program code, for example, whether stored in a storage medium, loaded into and/or executed by a computer, or as data signal 54 transmitted whether a modulated

carrier wave or not, over some transmission medium, such as over electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the computer program code is loaded into and executed by a computer, the computer becomes an apparatus capable of executing the method. When implemented on a general-purpose microprocessor, the computer program code segments configure the microprocessor to create specific logic circuits.

[44] It will be appreciated that the use of first and second or other similar nomenclature for denoting similar items is not intended to specify or imply any particular order unless otherwise stated.

[45] While the invention has been described with reference to an exemplary embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

- [1] A method for cell equalization in battery packs, comprising:
determining a state-of-charge for each cell of a plurality of cells;
determining at least one of a charge capacity and a discharge capacity for each cell of said plurality of cells; and
equalizing one or more cells of said plurality of cells, when at least one of;
a charge capacity of at least one cell of said plurality of cells is lower than a charge capacity of an other cell of said plurality of cells by a selected threshold, and
a discharge capacity of at least one cell of said plurality of cells is lower than a discharge capacity of an other cell of said plurality of cells by a selected threshold.
- [2] The method of claim 1 wherein determining said charge capacity is performed by calculating a difference between a selected maximum state-of-charge for said each cell and a present state-of-charge for said each cell.
- [3] The method of claim 2 wherein determining said charge capacity is further performed by multiplying said difference by a total capacity for said each cell.
- [4] The method of claim 3 wherein determining said charge capacity is further performed employing a Coulombic efficiency calculation.
- [5] The method of claim 2 wherein determining said charge capacity is further performed by multiplying said difference by a nominal capacity for said each cell.
- [6] The method of claim 5 wherein determining said charge capacity is further performed employing a Coulombic efficiency calculation.
- [7] The method of claim 2 wherein said equalizing is performed by depleting some charge from one or more cells of said plurality of cells having charge capacity less than a charge capacity of a selected cell from said plurality of cells by a selected threshold.
- [8] The method of claim 7, wherein said one or more cells having charge capacity less than a charge capacity of a selected cell from said plurality of cells by a selected threshold is determined by sorting said plurality of cells by charge capacity.
- [9] The method of claim 1, wherein determining said discharge capacity is performed by calculating a difference between a present state-of-charge for said

- each cell and a selected minimum state-of-charge for said each cell.
- [10] The method of claim 9 wherein determining said discharge capacity is further performed by multiplying said difference by a total capacity for said each cell.
- [11] The method of claim 9 wherein determining said discharge capacity is further performed by multiplying said difference by a nominal capacity for said each cell.
- [12] The method of claim 9 wherein said equalizing is performed by adding some charge to one or more cells of said plurality of cells having discharge capacity less than a discharge capacity of a selected cell from said plurality of cells by a selected threshold.
- [13] The method of claim 12 wherein said one or more cells having discharge capacity less than a discharge capacity of a selected cell from said plurality of cells by a selected threshold is determined by sorting said plurality of cells by discharge capacity.
- [14] The method of claim 1 wherein said equalizing is performed by moving charge from a first one or more cells to another one or more cells of said plurality of cells.
- [15] The method of claim 1 wherein equalizing is only performed when a difference between a selected maximum state-of-charge and a selected minimum state-of-charge of said plurality of cells meets or exceeds a selected threshold.
- [16] The method of claim 1 wherein state-of-charge is determined using a form of at least one of a Kalman filter, a dual Kalman filter, an extended Kalman filter, and a dual extended Kalman filter.
- [17] The method of claim 1 wherein said equalizing is only performed when a selected state-of-charge estimate falls outside an error bound of another selected state-of-charge estimate by a selected threshold.
- [18] The method of claim 17 wherein said equalizing is performed when a selected state-of-charge estimate falls outside an error bound of another selected state-of-charge estimate by a selected threshold where said error bound are computed using a state of charge estimation error covariance estimate.
- [19] The method of claim 1 wherein said equalizing is terminated if a difference between a selected maximum discharge capacity and a selected minimum discharge capacity and a difference between a selected maximum charge capacity and selected minimum charge capacity falls within a selected threshold.
- [20] The method of claim 1 wherein said equalizing is terminated if a cell is targeted

for both adding charge and depleting charge.

- [21] A method for cell equalization in battery packs, comprising:
determining a state-of-charge for each cell of a plurality of cells;
prioritizing said plurality of cells according to state-of-charge; and
equalizing said plurality of cells according to said prioritizing.
- [22] The method of claim 21 wherein said state-of-charge is determined using a form of Kalman filtering.
- [23] The method of claim 21 wherein said state-of-charge is determined using an extended Kalman filter.
- [24] The method of claim 22 wherein equalizing is only performed when a difference between a selected maximum state-of-charge and a selected minimum state-of-charge of said plurality of cells meets or exceeds a selected threshold.
- [25] A system for cell equalization in battery packs, comprising:
a battery pack with a plurality of cells;
a sensor in operable communication with at least two cells of said plurality of cells configured to facilitate determination of state of charge for each cell of said at least two cells; and
a controller in operable communication with said sensor and said plurality of cells;
wherein said controller is configured to to equalize charge of a cell of said at least two cells of said plurality of cells based on a state-of-charge for each cell of said plurality of cells.
- [26] The system of claim 25 further including a device configured to equalize charge of a cell of said at least two cells of said plurality of cells in operable communication with said plurality of cells and said controller.
- [27] The system of claim 25 further including said controller determining at least one of a charge capacity and a discharge capacity for each cell of said plurality of cells; and
equalizing one or more cells of said plurality of cells, when at least one of;
a charge capacity of at least one cell of said plurality of cells is lower than a charge capacity of an other cell of said plurality of cells by a selected threshold, and
a discharge capacity of at least one cell of said plurality of cells is lower than a discharge capacity of an other cell of said plurality of cells by a selected threshold.

- [28] The system of claim 27 wherein determining said charge capacity is performed by calculating a difference between a selected maximum state-of-charge for said each cell and said present state-of-charge for said each cell.
- [29] The system of claim 28 wherein determining said charge capacity is further performed by multiplying said difference by a total capacity for said each cell.
- [30] The system of claim 29 wherein determining said charge capacity is further performed employing a Coulombic efficiency calculation.
- [31] The system of claim 27 wherein determining said charge capacity is further performed by multiplying said difference by a nominal capacity for said each cell.
- [32] The system of claim 31 wherein determining said charge capacity is further performed employing a Coulombic efficiency calculation.
- [33] The system of claim 25 wherein said equalizing is performed by depleting some charge from one or more cells of said plurality of cells having charge capacity less than a charge capacity of a selected cell from said plurality of cells by a selected threshold.
- [34] The system of claim 33 wherein said one or more cells having charge capacity less than a charge capacity of a selected cell from said plurality of cells by a selected threshold is determined by sorting said plurality of cells by charge capacity.
- [35] The system of claim 25 wherein determining said discharge capacity is performed by calculating a difference between a present state-of-charge for said at least one cell and a selected minimum state-of-charge for said each cell.
- [36] The system of claim 35 wherein determining said discharge capacity is further performed by multiplying said difference by a total capacity for said each cell.
- [37] The system of claim 35 wherein determining said discharge capacity is further performed by multiplying said difference by a nominal capacity for said each cell.
- [38] The system of claim 35 wherein equalizing charge is performed by adding some charge to one or more cells of said plurality of cells having discharge capacity less than a discharge capacity of a selected cell from said plurality of cells by a selected threshold.
- [39] The system of claim 38 wherein said one or more cells having discharge capacity less than a discharge capacity of a selected cell from said plurality of cells by a selected threshold is determined by sorting said plurality of cells by discharge

capacity.

- [40] The system of claim 25, wherein equalizing charge is performed by moving charge from a first one or more cells to another one or more cells of said plurality of cells.
- [41] The system of claim 25 wherein equalizing charge of a cell is only performed when a difference between a selected maximum state-of-charge and a selected minimum state-of-charge of said plurality of cells meets or exceeds a selected threshold.
- [42] The system of claim 25 wherein state-of-charge is determined using a form of at least one of a Kalman filter, a dual Kalman filter, an extended Kalman filter, and a dual extended Kalman filter.
- [43] The system of claim 25 wherein equalizing charge is only performed when a selected state-of-charge estimate falls outside an error bound of another selected state-of-charge estimate by a selected threshold.
- [44] The system of claim 43 wherein said equalizing charge is performed when a selected state-of-charge estimate falls outside an error bound of another selected state-of-charge estimate by a selected threshold where said error bound are computed using a state of charge estimation error covariance estimate.
- [45] The system of claim 25 wherein equalizing charge is terminated if a difference between a selected maximum discharge capacity and a selected minimum discharge capacity and a difference between a selected maximum charge capacity and selected minimum charge capacity falls within a selected threshold.
- [46] The system of claim 25 wherein equalizing charge is terminated if a cell is targeted for both adding charge and depleting charge.
- [47] A system for cell equalization in battery packs, comprising:
a means for determining a state-of-charge for each cell of a plurality of cells;
a means for determining at least one of a charge capacity and a discharge capacity for each cell of said plurality of cells; and
a means for equalizing one or more cells of said plurality of cells, when at least one of;
a charge capacity of at least one cell of said plurality of cells is lower than a charge capacity of an other cell of said plurality of cells by a selected threshold, and
a discharge capacity of at least one cell of said plurality of cells is lower than a discharge capacity of an other cell of said plurality of cells by a selected

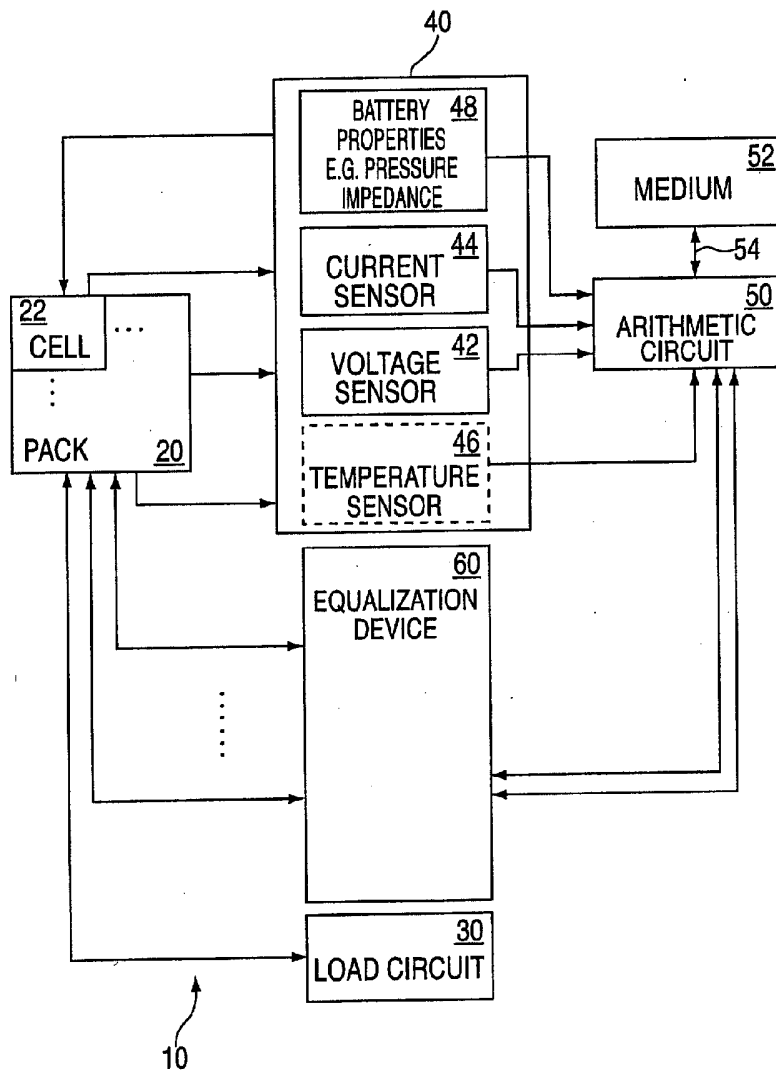
threshold.

[48]

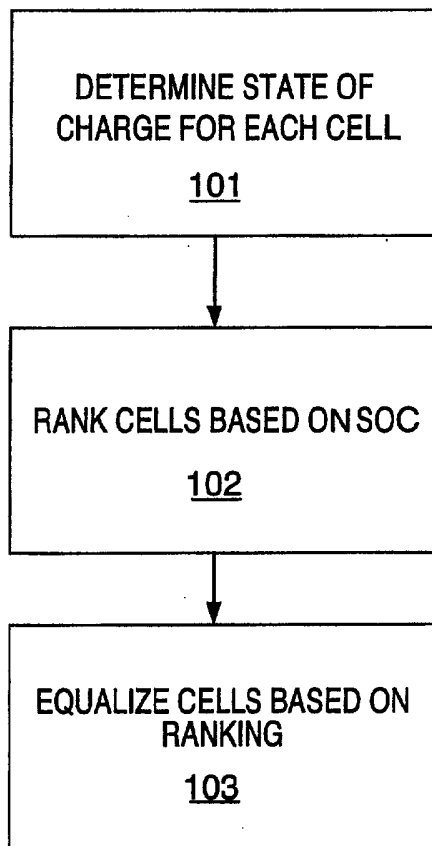
A storage medium encoded with a machine-readable computer program code, wherein said storage medium includes instructions for causing a computer to implement a method for cell equalization in battery packs comprising:
determining a state-of-charge for each cell of a plurality of cells;
determining at least one of a charge capacity and a discharge capacity for each cell of said plurality of cells; and
equalizing one or more cells of said plurality of cells, when at least one of;
a charge capacity of at least one cell of said plurality of cells is lower than a charge capacity of an other cell of said plurality of cells by a selected threshold, and
a discharge capacity of at least one cell of said plurality of cells is lower than a discharge capacity of an other cell of said plurality of cells by a selected threshold.

A computer data signal embodied in a computer readable medium said computer data signal comprising code configured to cause a computer to implement a method for cell equalization in battery packs comprising:
determining a state-of-charge for each cell of a plurality of cells;
determining at least one of a charge capacity and a discharge capacity for each cell of said plurality of cells; and
equalizing one or more cells of said plurality of cells, when at least one of;
a charge capacity of at least one cell of said plurality of cells is lower than a charge capacity of an other cell of said plurality of cells by a selected threshold, and
a discharge capacity of at least one cell of said plurality of cells is lower than a discharge capacity of an other cell of said plurality of cells by a selected threshold.

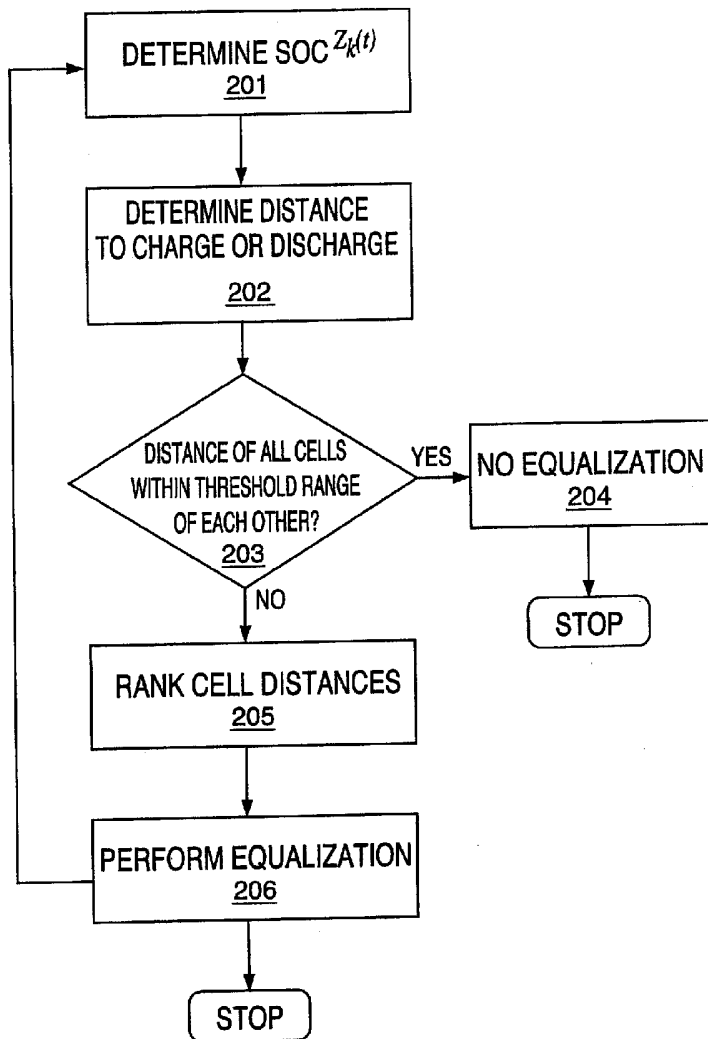
[Fig. 1]



[Fig. 2]



[Fig. 3]



VIII-5-1	Declaration: Non-prejudicial disclosure or exceptions to lack of novelty Declaration as to non-prejudicial disclosures or exceptions to lack of novelty (Rules 4.17(v) and 51bis.1(a)(v)): Name (LAST, First)	in relation to this international application LG CHEM, LTD. declares that the subject matter claimed in this international application was disclosed as follows:
VIII-5-1(i)	Kind of disclosure:	publication
VIII-5-1(i)	Date of disclosure:	28 May 2004 (28.05.2004)
VIII-5-1(i)	Title of disclosure:	ELSEVIER (Journal of Powers Sources)
VIII-5-1(i)	Place of disclosure:	
VIII-5-1(v)	This declaration is made for the purposes of:	all designations

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2004/003104

A. CLASSIFICATION OF SUBJECT MATTER

IPC7 H01M 10/44

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7 H01M 10/42, H02J 7/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PAJ, E-KIPASS, E-SPACENET

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6452363 B (C.E.NIEHOFF & CO) 17 SEPTEMBER 2002 See claims	1-48
A	US 5666041 A (THE UNIVERSITY OF TOLEDO) 9 SEPTEMBER 1997 See claims and figures	1-48
A	US 6534954 B (COMPACT POWER INC) 18 MARCH 2003 See the whole document	1-48
A	JP 2002-75461 A (TOYOTA MOTOR CORP) 15 MARCH 2002 See the whole document	1-48

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
 "E" earlier application or patent but published on or after the international filing date
 "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
 "O" document referring to an oral disclosure, use, exhibition or other means
 "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
 "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
 "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
 "&" document member of the same patent family

Date of the actual completion of the international search

25 JULY 2005 (25.07.2005)

Date of mailing of the international search report

25 JULY 2005 (25.07.2005)

Name and mailing address of the ISA/KR



Korean Intellectual Property Office
920 Dunsan-dong, Seo-gu, Daejeon 302-701,
Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

KIM, Seung Soo

Telephone No. 82-42-481-5581



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR2004/003104

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6452363 B	17.09.2002	NONE	
US 5666041 A	09.09.1997	NONE	
US 6534954 B	18.03.2003	NONE	
JP 2002-75461 A	15.03.2002	NONE	