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(54) **SYSTEM AND METHOD FOR CHARGING AND DISCHARGING A LI-ION BATTERY PACK**

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H02J 7/00 (2006.01)

(52) **U.S. Cl.** **320/118**; 320/116; 320/119; 320/122; 320/132

(58) **Field of Classification Search** 320/118, 320/122

See application file for complete search history.

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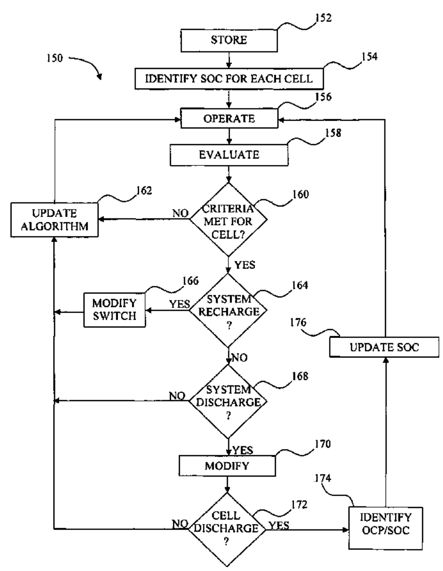
(57) **ABSTRACT**

An electrochemical battery system in one embodiment includes a plurality of first electrochemical cells, a memory in which command instructions are stored, and a processor configured to execute the command instructions to (i) evaluate each of the plurality of first electrochemical cells, and (ii) selectively connect a first of the plurality of first electrochemical cells to a power provider based upon the evaluation while selectively isolating a second of the plurality of first electrochemical cells from the power provider based upon the evaluation.

19 Claims, 5 Drawing Sheets



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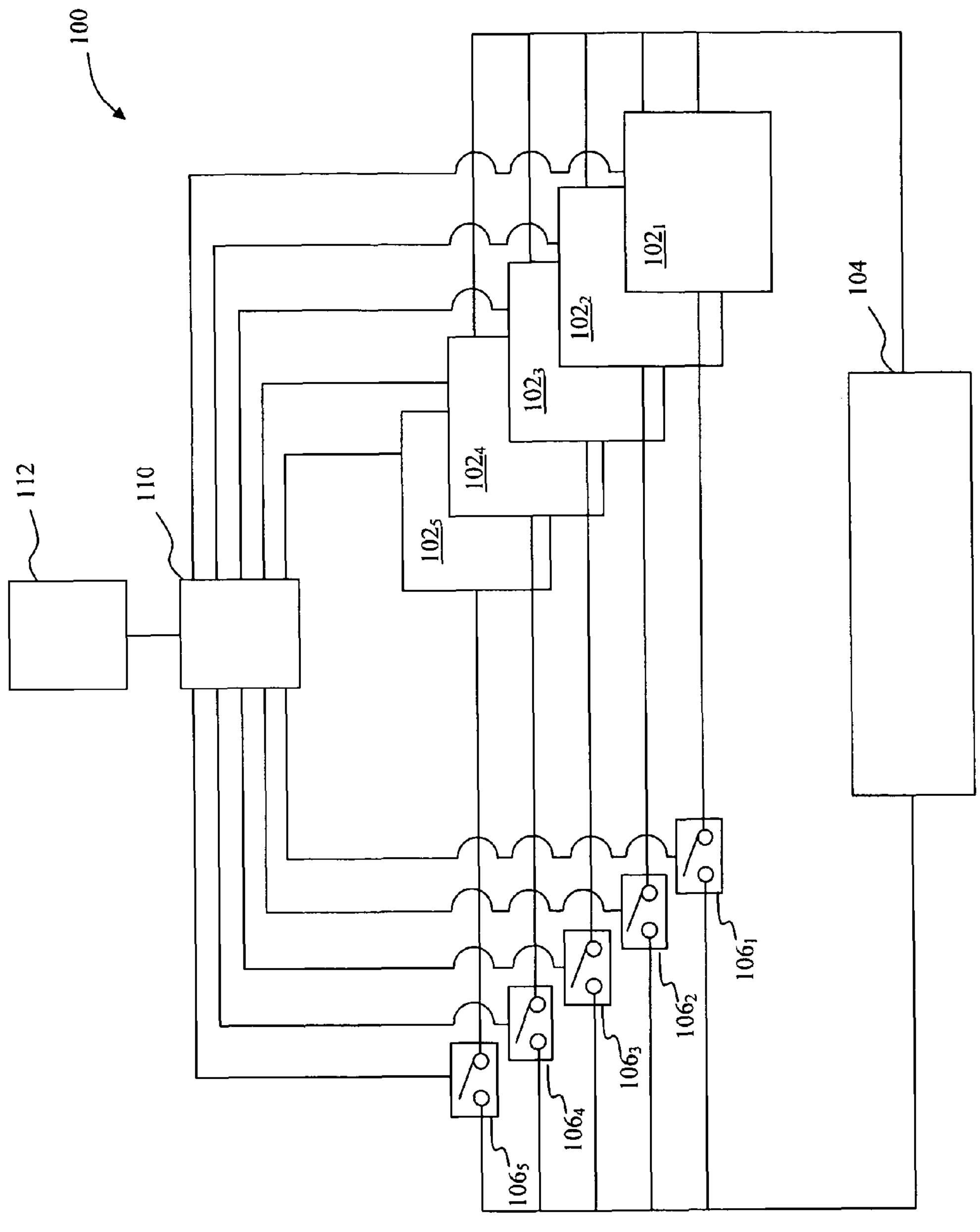
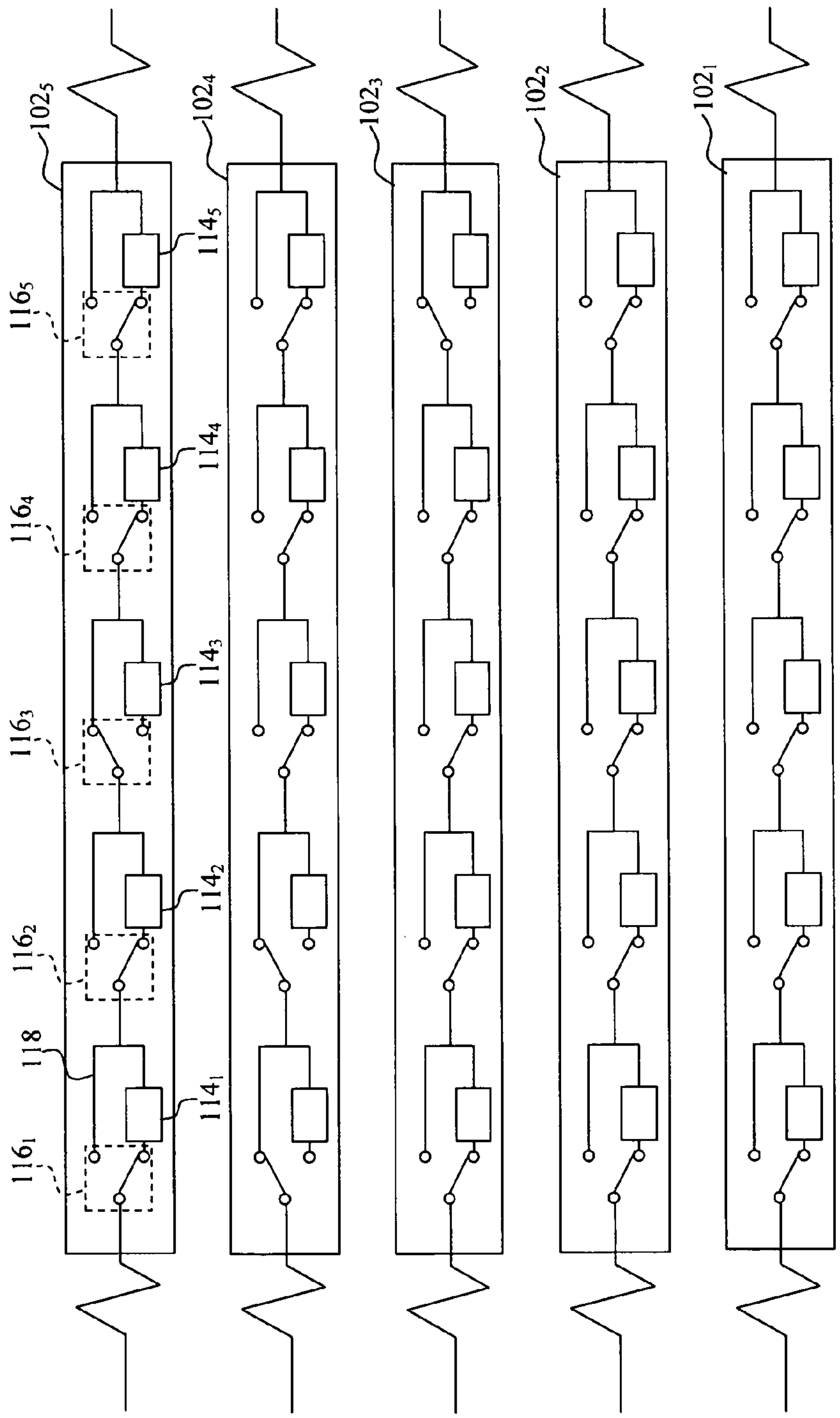

100
112
110
102_1
102_2
102_3
102_4
102_5
104
106_1
106_2
106_3
106_4
106_5

FIG. 1



102_5
102_4
102_3
102_2
102_1
116_5
114_5
116_4
114_4
116_3
114_3
116_2
114_2
118
116_1
114_1

FIG. 2

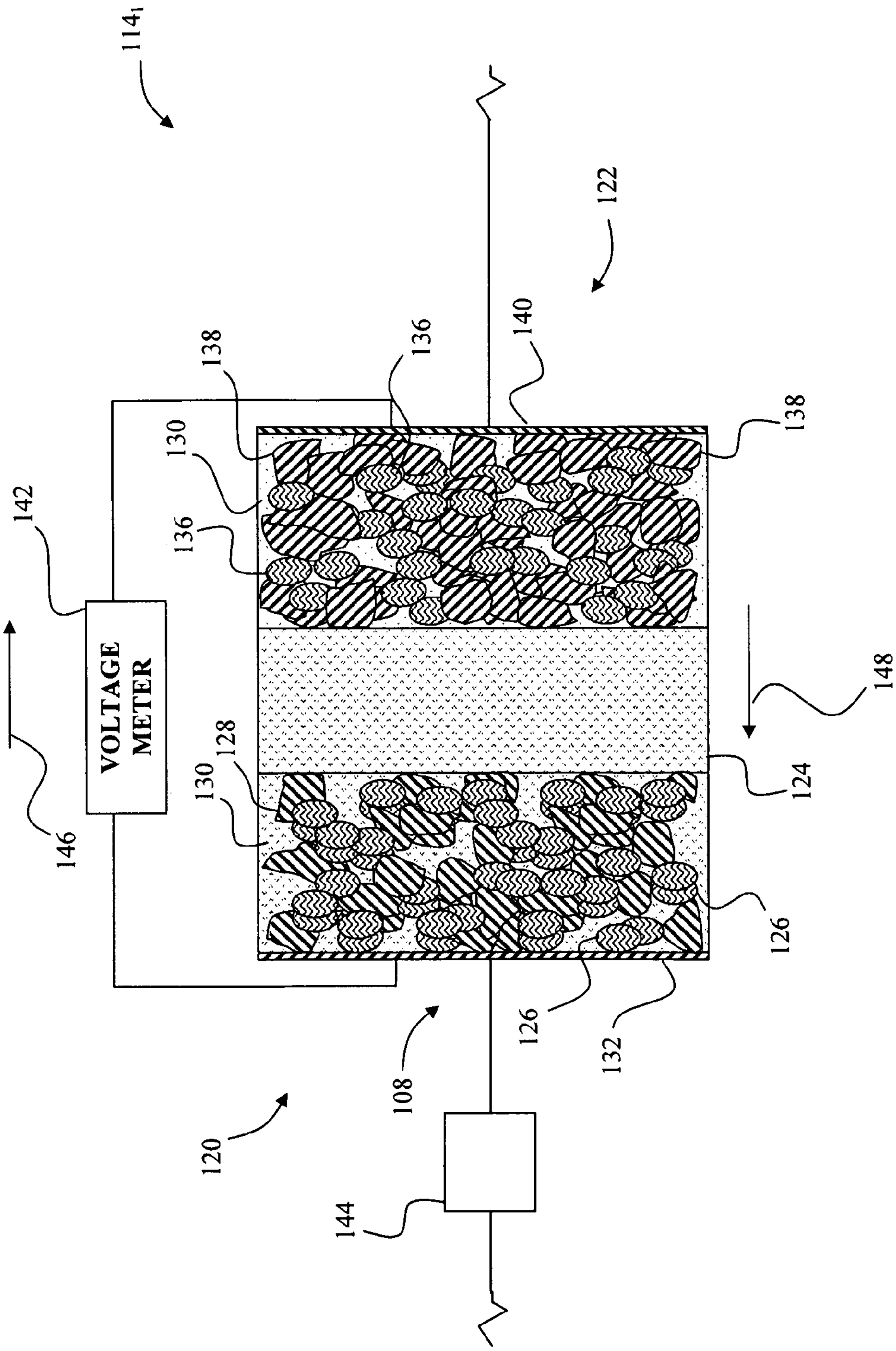
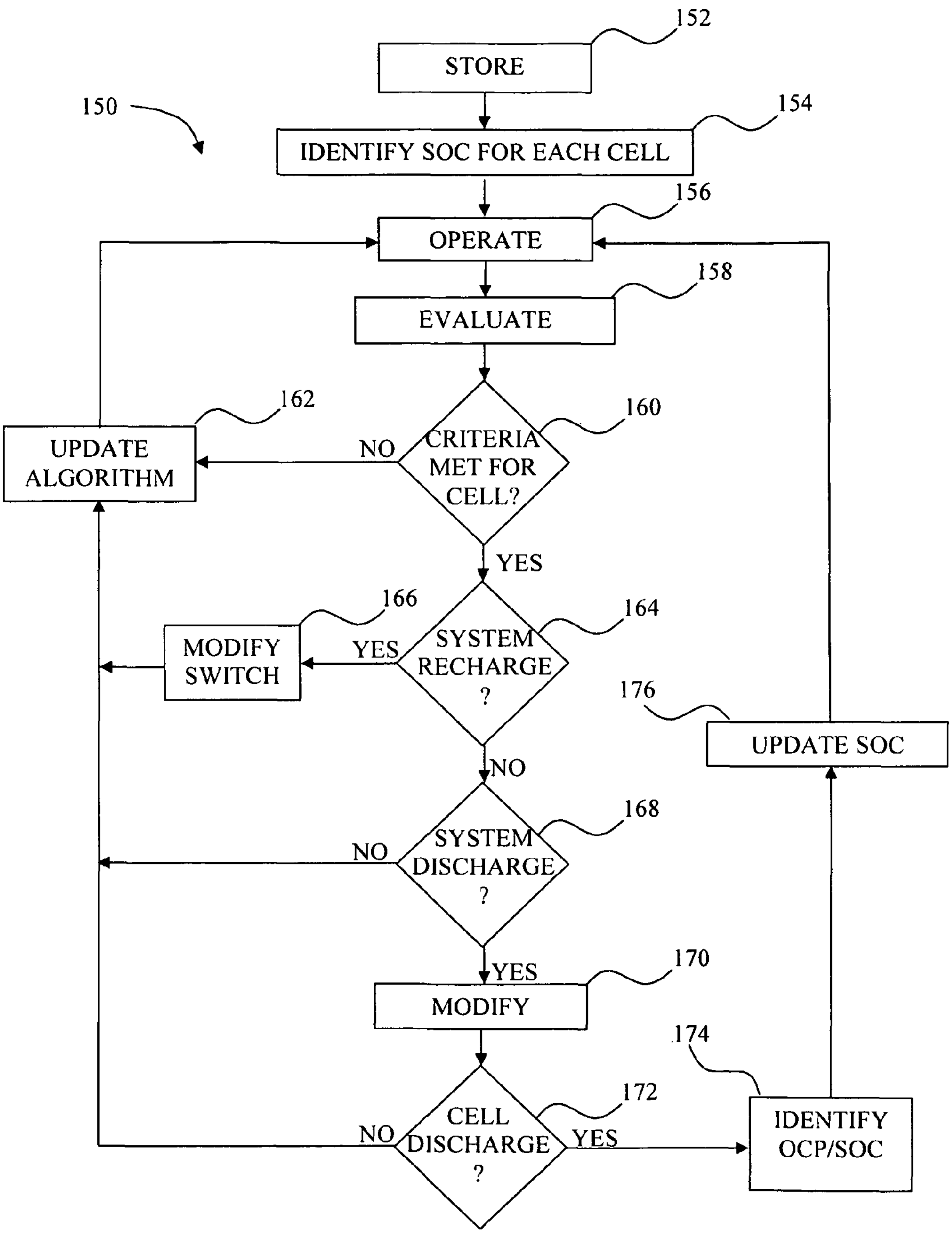

114₁
122
138
136
140
130
142
136
138
VOLTAGE METER
148
124
128
130
146
126
126
132
108
120
144

FIG. 3



152
STORE
150
154
IDENTIFY SOC FOR EACH CELL
156
OPERATE
158
EVALUATE
162
160
UPDATE ALGORITHM
NO
CRITERIA MET FOR CELL?
YES
166
164
MODIFY SWITCH
YES
SYSTEM RECHARGE ?
176
NO
UPDATE SOC
168
NO
SYSTEM DISCHARGE ?
YES
170
MODIFY
174
172
NO
CELL DISCHARGE ?
YES
IDENTIFY OCP/SOC

FIG. 4

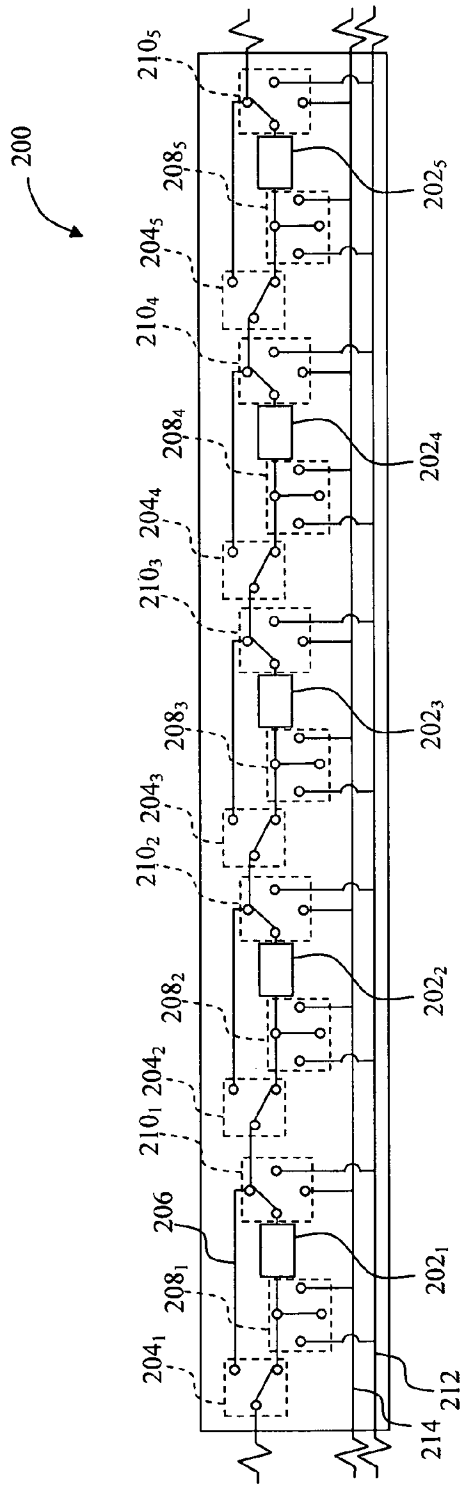

200
210_5
208_5
202_5
204_5
210_4
208_4
202_4
204_4
210_3
208_3
202_3
204_3
210_2
208_2
202_2
204_2
210_1
206
202_1
208_1
204_1
212
214

FIG. 5

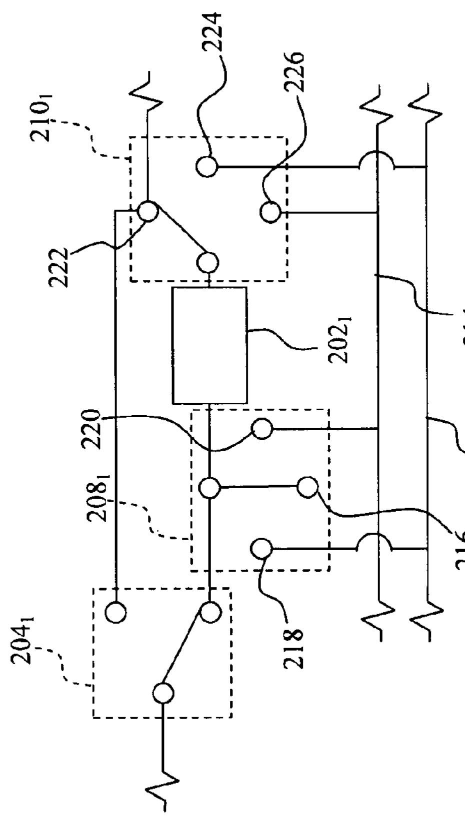

210_1
224
226
222
202_1
214
220
208_1
216
212
218
204_1

FIG. 6

SYSTEM AND METHOD FOR CHARGING AND DISCHARGING A LI-ION BATTERY PACK

Cross-reference is made to U.S. Utility patent application Ser. No. 12/437,576 entitled "Li-ion Battery with Selective Moderating Material" by John F. Christensen et al., which was filed on May 8, 2009; U.S. Utility patent application Ser. No. 12/437,592 entitled "Li-ion Battery with Blended Electrode" by John F. Christensen et al., which was filed on May 8, 2009; U.S. Utility patent application Ser. No. 12/437,606 entitled "Li-ion Battery with Variable Volume Reservoir" by John F. Christensen et al., which was filed on May 8, 2009; U.S. Utility patent application Ser. No. 12/437,622 entitled "Li-ion Battery with Over-charge/Over-discharge Failsafe" by John F. Christensen et al., which was filed on May 8, 2009; U.S. Utility patent application Ser. No. 12/437,643 entitled "System and Method for Pressure Determination in a Li-ion Battery" by John F. Christensen et al., which was filed on May 8, 2009; U.S. Utility patent application Ser. No. 12/437,745 entitled "Li-ion Battery with Load Leveler" by John F. Christensen et al., which was filed on May 8, 2009; U.S. Utility patent application Ser. No. 12/437,774 entitled "Li-ion Battery with Anode Coating" by Boris Kozinsky et al., which was filed on May 8, 2009; U.S. Utility patent application Ser. No. 12/437,791 entitled "Li-ion Battery with Anode Expansion Area" by Boris Kozinsky et al., which was filed on May 8, 2009; U.S. Utility patent application Ser. No. 12/437,822 entitled "Li-ion Battery with Porous Silicon Anode" by Boris Kozinsky et al., which was filed on May 8, 2009; U.S. Utility patent application Ser. No. 12/437,873 entitled "Li-ion Battery with Rigid Anode Framework" by Boris Kozinsky et al., which was filed on May 8, 2009; and U.S. Utility Patent Application Ser. No. 12/463,024 entitled "System and Method for Charging and Discharging a Li-ion Battery" by Nalin Chaturvedi et al., which was filed on May 8, 2009, the entirety of each of which is incorporated herein by reference. The principles of the present invention may be combined with features disclosed in those patent applications.

FIELD OF THE INVENTION

This invention relates to batteries and more particularly to lithium-ion batteries.

BACKGROUND

Batteries are a useful source of stored energy that can be incorporated into a number of systems. Rechargeable lithium-ion batteries are attractive energy storage systems for portable electronics and electric and hybrid-electric vehicles because of their high specific energy compared to other electrochemical energy storage devices. In particular, batteries with a form of lithium metal incorporated into the negative electrode afford exceptionally high specific energy (in Wh/kg) and energy density (in Wh/L) compared to batteries with conventional carbonaceous negative electrodes.

When high-specific-capacity negative electrodes such as lithium are used in a battery, the maximum benefit of the capacity increase over conventional systems is realized when a high-capacity positive electrode active material is also used. Conventional lithium-intercalating oxides (e.g., $LiCoO_2$, $LiNi_{0.8}Co_{0.15}A_{0.05}O_2$, $Li_{1.1}Ni_{0.3}Co_{0.3}Mn_{0.3}O_2$) are typically limited to a theoretical capacity of ~280 mAh/g (based on the mass of the lithiated oxide) and a practical capacity of 180 to 250 mAh/g. In comparison, the specific capacity of lithium metal is about 3863 mAh/g. The highest theoretical capacity achievable for a lithium-ion positive electrode is 1168 mAh/g (based on the mass of the lithiated material), which is shared by Li_2S and Li_2O_2. Other high-capacity materials including BiF_3 (303 mAh/g, lithiated) and FeF_3 (712 mAh/g, lithiated) are identified in Amatucci, G. G. and N. Pereira, *Fluoride based electrode materials for advanced energy storage devices*. Journal of Fluorine Chemistry, 2007, 128(4): p. 243-262. All of the foregoing materials, however, react with lithium at a lower voltage compared to conventional oxide positive electrodes, hence limiting the theoretical specific energy. The theoretical specific energies of the foregoing materials, however, are very high (>800 Wh/kg, compared to a maximum of ~500 Wh/kg for a cell with lithium negative and conventional oxide positive electrodes).

Lithium/sulfur (Li/S) batteries are particularly attractive because of the balance between high specific energy (i.e., >350 Wh/kg has been demonstrated), rate capability, and cycle life (>50 cycles). Only lithium/air batteries have a higher theoretical specific energy. Lithium/air batteries, however, have very limited rechargeability and are still considered primary batteries.

Thus the advantage of using a Li metal anode is the much higher energy density of the entire cell, as compared to cells with graphitic or other intercalation anodes. A disadvantage of using pure Li metal is that lithium is highly reactive. Accordingly, the lithium metal can be damaged by other chemical species in the cell. Additionally, the lithium metal has a propensity to grow metallic dendrites when the cell is being charged. Metallic dendrites can then puncture the separator and cause an internal short of the cell.

Moreover, repeated cycling of a Li-anode cell results in significant morphology changes. The initially dense metal, after a certain number of cycles, develops surface roughness and a sponge-like morphology. This morphology is potentially dangerous due to high surface area which increases the chance for, and severity of, runaway reactions.

What is needed therefore is a battery system and method that reduces the potential for dendrite formation and undesired morphological changes in the anode. A system and method which could also be used to provide more accurate state of charge determination in a cell would be beneficial.

SUMMARY

An electrochemical battery system in one embodiment includes a plurality of first electrochemical cells, a memory in which command instructions are stored, and a processor configured to execute the command instructions to (i) evaluate each of the plurality of first electrochemical cells, and (ii) selectively connect a first of the plurality of first electrochemical cells to a power provider based upon the evaluation while selectively isolating a second of the plurality of first electrochemical cells from the power provider based upon the evaluation.

In accordance with another embodiment, an electrochemical battery system, includes a first electrochemical cell, a second electrochemical cell, a memory in which command instructions are stored, and a processor configured to execute the command instructions to (i) evaluate the first electrochemical cell and the second electrochemical cell, and (ii) selectively connect the first electrochemical cell to a power provider based upon the evaluation while selectively isolating the second electrochemical cell from the power provider based upon the evaluation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts a simplified schematic of a battery system including several electrochemical cell packs which can be independently controlled for charging or discharging operations;

FIG. **2** depicts a simplified schematic of the cell packs of FIG. **1** showing the independently controlled connection switches for each of the electrochemical cells within the electrochemical cell packs;

FIG. **3** depicts a schematic of one of the electrochemical cells of FIG. **1** showing amp meters and a voltage meter which can be used in executing a charging and discharging strategy;

FIG. **4** depicts a flow diagram of a procedure that may be performed by the battery system of FIG. **1** to independently control charging and discharging operations of individual electrochemical cells;

FIG. **5** depicts a simplified schematic of an alternative cell pack showing independently controlled connection switches for each of the electrochemical cells within the electrochemical cell pack to provide charge shifting between power providers; and

FIG. **6** depicts an enlarged simplified schematic of one of the electrochemical cells within the electrochemical cell pack of FIG. **5**.

DESCRIPTION

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and described in the following written specification. It is understood that no limitation to the scope of the invention is thereby intended. It is further understood that the present invention includes any alterations and modifications to the illustrated embodiments and includes further applications of the principles of the invention as would normally occur to one skilled in the art to which this invention pertains.

FIG. **1** depicts a battery system **100** including several lithium-ion battery cell packs $\mathbf{102}_x$. In the embodiment of FIG. **1**, five battery cell packs $\mathbf{102}_{1\text{-}5}$ are depicted. In alternative embodiments, more or fewer battery cell packs of different or the same chemistry may be provided. Each of the lithium-ion battery cell packs $\mathbf{102}_x$ is selectively connected to a load or voltage source **104** through a respective switch $\mathbf{106}_x$. Each of the switches $\mathbf{106}_x$ are controlled by a processor **110** which is operably connected to a memory **112**. Various command instructions, discussed in further detail below, are programmed into the memory **112**. The processor **110** is operable to execute the command instructions programmed into the memory **112**.

The lithium-ion battery cell packs $\mathbf{102}_x$ in this embodiment are identical and are described in further detail with reference to FIG. **2** and the lithium-ion battery cell pack $\mathbf{102}_5$. The lithium-ion battery cell pack $\mathbf{102}_5$ includes five lithium-ion battery cells $\mathbf{114}_{1\text{-}5}$. A two-way connection switch $\mathbf{116}_{1\text{-}5}$ is associated with each of the battery cells $\mathbf{114}_{1\text{-}5}$. The connection switches $\mathbf{116}_{1\text{-}5}$, which are independently controlled by the processor **110** (control lines are omitted for clarity), can alternatively connect the respective battery cells $\mathbf{114}_{1\text{-}5}$ to an internal battery cell circuit **118** or bypass the respective battery cell $\mathbf{114}_{1\text{-}5}$. In FIG. **2**, the connection switches $\mathbf{116}_{1,\,2,\,4,\,and\,5}$ are positioned to connect the respective battery cells $\mathbf{114}_{1,\,2,\,4,\,and\,5}$ to the battery cell circuit **118** while the connection switch $\mathbf{116}_3$ is positioned to a bypass position whereby the respective battery cell $\mathbf{114}_3$ is effectively electrically isolated from the battery cell circuit **118**.

The lithium-ion battery cells $\mathbf{114}_{1\text{-}5}$ in this embodiment are identical and are described in further detail with reference to the lithium-ion battery cell $\mathbf{114}_1$ shown in FIG. **3**. The lithium ion cell $\mathbf{114}_1$ includes a negative electrode **120**, a positive electrode **122**, and a separator region **124** between the negative electrode **120** and the positive electrode **122**. The negative electrode **120** includes active materials **126** into which lithium can be inserted, inert materials **128**, electrolyte **130** and a current collector **132**.

The negative electrode **120** may be provided in various alternative forms. The negative electrode **120** may incorporate dense Li metal or a conventional porous composite electrode (e.g., graphite particles mixed with binder). Incorporation of Li metal is desired since the Li metal affords a higher specific energy than graphite.

The separator region **124** includes an electrolyte with a lithium cation and serves as a physical and electrical barrier between the negative electrode **120** and the positive electrode **122** so that the electrodes are not electronically connected within the battery cell $\mathbf{114}_1$ while allowing transfer of lithium ions between the negative electrode **120** and the positive electrode **122**.

The positive electrode **122** includes active material **136** into which lithium can be inserted, inert material **138**, the electrolyte **130**, and a current collector **140**. The active material **136** includes a form of sulfur and may be entirely sulfur. A voltage meter **142** is configured to obtain the voltage between the anode **120** and the cathode **122**, and a coulomb counter **144** is provided to detect current flow into and out of the battery cell $\mathbf{114}_1$. The coulomb counter **144**, which may be located anywhere along the circuit **118** or adjacent to the cell pack $\mathbf{102}_1$, may be used to detect current flow into and out of all of the battery cells $\mathbf{114}_{1\text{-}5}$ in the cell pack $\mathbf{102}_1$ since the same current will be flowing through each of the battery cells $\mathbf{114}_{1\text{-}5}$ connected to the circuit **118**.

The lithium-ion battery cells $\mathbf{114}_x$ operate in a manner similar to the lithium-ion battery cell disclosed in U.S. patent application Ser. No. 11/477,404, filed on Jun. 28, 2006, the contents of which are herein incorporated in their entirety by reference. In general, with reference to battery cell $\mathbf{114}_1$, electrons are generated at the negative electrode **120** during discharging and an equal amount of electrons are consumed at the positive electrode **122** as lithium and electrons move in the direction of the arrow **146** of FIG. **2**.

In the ideal discharging of the cell $\mathbf{114}_1$, the electrons are generated at the negative electrode **120** because there is extraction via oxidation of lithium ions from the active material **126** of the negative electrode **120**, and the electrons are consumed at the positive electrode **122** because there is reduction of lithium ions into the active material **136** of the positive electrode **122**. During discharging, the reactions are reversed, with lithium and electrons moving in the direction of the arrow **148**.

Returning to FIG. **1**, the electrochemical battery cell packs $\mathbf{102}_{1\text{-}5}$ may be used to selectively power the load/source **104** during normal discharge operations by selectively controlling the switches $\mathbf{106}_{1\text{-}5}$ shut. Similarly, the electrochemical battery cell packs $\mathbf{102}_{1\text{-}5}$ may be selectively recharged by the load/source **104** during normal charging operations by selectively controlling the switches $\mathbf{106}_{1\text{-}5}$ shut. Charging and discharging of the lithium-ion battery cells $\mathbf{114}_x$ within the cell packs $\mathbf{102}_x$ connected to the load **104** can further be selectively controlled by selectively controlling the associated connection switch $\mathbf{116}_x$.

In practice, users frequently charge electrochemical cells prior to fully discharging the cells. Such practice, while convenient to the user or necessitated by operational considerations, increases the potential for dendrite formation and for non-uniform morphology changes in the anode. Moreover, as the capacity of a particular cell fades or otherwise decreases over the life of the cell, the relationship between the state of charge of the cell and the open cell potential (OCP) of the cell changes. The OCP of a cell is commonly incorporated into SOC determinations. Thus, as a cell ages, SOC determination for the cell becomes less accurate. The failure to fully discharge all of the cells also exacerbates degradation of the cells with greater capacity, as those cells are more aggressively used than the cells with lower capacity when the battery voltage is higher.

Accordingly, in one embodiment, the processor **110** executes command instructions stored within the memory **112** in accordance with a procedure **150** of FIG. **4** to selectively charge and discharge the electrochemical cells **114**$_x$. Initially, criteria for operating the system **100** are stored in the memory **112** at block **152**. The criteria may in the form of an algorithm with different weights provided for different factors. By way of example, the time since a cell was last fully discharged may be given a first weight and the last known cell capacity may be given another weight. Thus, while two cells may have last been fully discharged at the same time, the cell with a lower capacity may receive a higher score using the stored algorithm. Since a "fully discharged" cell typically has some capacity remaining, the definition of "fully discharged" may vary from one system to another depending upon the cell chemistry, the application, and other criteria.

At block **154**, the initial OCP/SOC relationship for each individual cell is stored in the memory **112**. This information may be obtained in any desired manner. The system **100** is then operated with the processor **110** controlling the position of the switches **106**$_{1\text{-}5}$ and the connection switches **116**$_x$ at block **156**.

As the system **100** is operated, the processor **110** receives data from the voltage meters **142** and the coulomb counters **144** associated with each of the cells **114**$_x$. These data are used by the processor **110** to identify a present SOC for each of the cells **114**$_x$. The identified SOC and other data available to the processor **110** are used at the block **158** to evaluate the present condition of each of the cells using the criteria stored at block **152**. If, based upon the evaluation, the criteria is not met for selective control of one or more of the cells **114**$_x$ at block **160**, then the algorithm is updated at block **162** and the processor **110** continues to operate the system **100**. Updates to the algorithm may include, for example, modifying the weight given to the time since the cell was last fully discharged. Thus, the weight associated with a particular factor evaluated by the processor **110** need not exhibit a linear characteristic as the cells age.

If at block **160** the criteria for selective control of a cell **114**$_x$ are met, the processor **110** ascertains the status of the system **100**. At block **164**, the processor **110** determines if the system **100** is being recharged. If the system **100** is being recharged, then at block **166** the processor **110** executes command instructions stored in the memory **112** to selectively control the switches **106**$_{1\text{-}5}$ and the connection switches **116**$_x$.

By way of example, the criteria stored in the memory **152** may include different thresholds which are used to prioritize actions. In one embodiment, a cell **114**$_x$ which has a SOC less than a predetermined threshold, which may be between 40 and 60% SOC, is preferably fully discharged prior to recharging, cells which are fully discharged are prioritized for charging, and cells greater than the predetermined threshold may be charged. The actual thresholds used for a particular embodiment may be differently selected based upon considerations such as chemistries involved, and the particular application.

In one example, the threshold is selected to be 40% SOC, the cell **114**$_1$ is at 30% SOC, the cell **114**$_2$ is at 20% SOC, the cell **114**$_3$ is fully discharged, the cell **114**$_4$ is at 80% SOC, and the cell **114**$_5$ is at 45% SOC. Accordingly, at block **166** when the load **104** is charging the cell packs **102**$_{1\text{-}5}$, the processor **110** controls the switch **106**$_5$ to the shut position and the connection switch **116**$_3$ to connect the cell **114**$_3$ to the circuit **118**. Thus, the cell **114**$_3$ receives a charging current.

The processor **110** may further evaluate the available charging current to optimize the rate of charge for the cells **114**$_x$ and other charging criteria to selectively charge cell **114**$_x$ in the battery packs **102**$_{1\text{-}4}$. The processor **110** further controls the connection switch **116**$_{1, 2, 4, \textit{and } 5}$ to the bypass position so that the cells **114**$_{1, 2, 4, \textit{and } 5}$ are not charged. Thus, the cell **114**$_3$ is charged prior to the other cells **114**$_x$ in the battery pack **102**$_5$.

Once the cell **114**$_3$ and other fully discharged cells are fully charged, the processor **110** controls the connection switch **116**$_3$ to the open position and, if charging current is still available, controls the connection switch **116**$_4$ to the closed position. Thus, the cell **114**$_4$, which is farthest from the 40% SOC threshold, is preferably charged before charging the cell **114**$_1$, the cell **114**$_2$, or the cell **114**$_5$. The next cell to be charged would thus be the cell **114**$_5$. Once the cell **114**$_5$ is charged, the processor **110** may either terminate charging, or charge the cells **114**$_{1 \textit{ and } 2}$, depending upon the criteria stored in the memory **112**. In alternative embodiments, the processor **110** may execute command instructions which do not allow a cell to be recharged until the cell has been discharged below another predetermined SOC threshold.

After the charging operation is completed for a particular cell **114**$_x$, the algorithm is updated at block **162** and the processor **110** continues to control operation of the system **100** at block **156**. The update may include data associated with the time of the last full discharge as well as SOC data. The SOC data may include the capacity of the particular cell **114**$_x$ with respect to voltage of the cell including a reset of the 0% SOC threshold for the cell **114**$_x$.

If at block **164**, the processor **110** determines that the system **100** is not being recharged, the processor **110** then determines if the system is discharging at block **168**. If the system is not being discharged at block **168**, the algorithm is updated at block **162** and the processor **110** awaits further operation of the system **100** at block **156**. If the system **100** is being discharged, then at block **170** the processor **110** executes command instructions stored in the memory **112** to selectively control the switches **106**$_{1\text{-}5}$ and the connection switches **116**$_x$. By way of example, with the SOC conditions identified in the example above, discharge of the cell **114**$_5$ may be prioritized.

When discharging is terminated for a particular cell **114**$_x$, the processor **110** identifies if the cell **114**$_x$ has been fully discharged. If the cell has not been fully discharged, then the algorithm is updated at block **162** and the processor **110** continues to operate the system **100** at block **156**. If the cell has been fully discharged at block **172**, then the procedure **150** continues to block **174**.

One advantage of the procedure of FIG. **3** is that by completely discharging a particular cell, the roughness in Li-anode can be reduced and hence the anode morphology is improved. Another important advantage occurs in improved accuracy for SOC estimation. Specifically, in addition to integration of current data, SOC estimators also rely on voltage measurement to improve SOC determination accuracy. By discharging a cell completely, the SOC estimate of the cell is reset to a value that is close to zero. By further incorporating measurement of the cell voltage and current obtained during full discharge and subsequent charging of the cell, the fully charged SOC may be accurately identified based upon the charged capacity and the theoretical capacity of the cell. Furthermore, the OCP/SOC relationship of the aged cell may be ascertained using the obtained data at block **174**. Thus, updated SOC data may be stored in the memory **112** at block **176** and the processor **110** continues to operate the system **100** at block **156**.

The procedure **150** may be modified to incorporate other criteria or factors in the control algorithm. By way of example, maintaining a certain number of fully charged cells may be given an increased weighting. The procedure **150** may further be modified to sequentially fully discharge at least one cell. Thus, the cell $\mathbf{114}_2$ may initially be preferentially discharged, with other cells connected to a load as needed. Once full discharge of the cell $\mathbf{114}_2$ is accomplished, the cell $\mathbf{114}_1$ may be preferentially discharged. The sequence may be specifically identified or randomly generated. In a further embodiment, the sequence is dependent upon a number of different criteria including time since last full discharge, cell capacity, etc.

In a further embodiment, the procedure **150** is modified to selectively transfer charge from a selected cell to another power provider. The power provider may be, for example, another one of the electrochemical cells $\mathbf{102}_x$, a power grid, or a flexible power source. A "power provider" as that term is used herein is thus a component or system which stores or generates electrical power.

By way of example, FIG. **5** depicts an electrochemical cell pack **200** with additional detail as to one embodiment enabling selective charge transfer between power providers. The cell pack **200** includes electrochemical cells $\mathbf{202}_{1\text{-}5}$. More or fewer cells $\mathbf{202}_x$ may be provided if desired. Each of the electrochemical cells $\mathbf{202}_{1\text{-}5}$ are associated with a respective connection switch $\mathbf{204}_{1\text{-}5}$ which can be used to selectively couple the respective electrochemical cell $\mathbf{202}_x$ to an electrochemical cell pack circuit **206**. The cell pack **200** is thus similar to the cell packs $\mathbf{102}_x$ and can be incorporated into the system **100** and controlled by the processor **110**.

Each of the electrochemical cells $\mathbf{202}_{1\text{-}5}$ are further associated with respective charge transfer switches $\mathbf{208}_x$ and $\mathbf{210}_x$. The charge transfer switches $\mathbf{208}_x$ and $\mathbf{210}_x$ can each be used to selectively couple the electrodes of the respective electrochemical cell $\mathbf{202}_x$ to a charge transfer line pair **212** and **214**. With reference to FIG. **6**, the charge transfer switch $\mathbf{208}_1$ is a three position switch including a neutral terminal **216**, a terminal **218** which is coupled with the charge transfer line **212**, and a terminal **220** which is coupled with the charge transfer line **214**. The charge transfer switch $\mathbf{210}_1$ is a three position switch including a circuit terminal **222**, a terminal **224** which is coupled with the charge transfer line **212**, and a terminal **226** which is coupled with the charge transfer line **214**.

By selective positioning of the connection switches $\mathbf{204}_x$, and the charge transfer switches $\mathbf{208}_x$ and $\mathbf{210}_x$, a processor such as the processor **110** can transfer charge between the electrochemical cells $\mathbf{202}_{1\text{-}5}$. By way of example, if the cell $\mathbf{202}_1$ is at 30% SOC, the cell $\mathbf{202}_2$ is at 20% SOC, the cell $\mathbf{202}_3$ is fully discharged, the cell $\mathbf{202}_4$ is at 80% SOC, and the cell $\mathbf{202}_5$ is at 45% SOC, and a charging current is available, the fully discharged cell $\mathbf{202}_3$ may be configured to receive the charging current. Additionally, the charge transfer switches $\mathbf{208}_2$, $\mathbf{210}_2$, $\mathbf{208}_5$, $\mathbf{210}_5$ can be configured to transfer charge from the cell $\mathbf{202}_2$ to the cell $\mathbf{202}_4$. Accordingly, as the cell $\mathbf{202}_3$ is charged from the circuit **206**, the cell $\mathbf{202}_2$ can be fully discharged by charging the cell $\mathbf{202}_4$.

In the event that the load/source **104** is the power grid or a flexible power source (such as a Vehicle-to-Grid V2G network), the criteria stored in the memory **112** may include a consideration of the time of day. By way of example, the processor **110** may control the system **100** to discharge cells above a lower SOC threshold and below an upper SOC threshold into the load/source **104** during peak power demand times if the power demand peaks during the day-time. The discharged cell may then be fully charged at a later, off-peak time. Thus, the consumer benefits by the difference in power pricing, while also improving the life of the battery by maintaining the anode morphology and thus improving cycle life.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same should be considered as illustrative and not restrictive in character. It is understood that only the preferred embodiments have been presented and that all changes, modifications and further applications that come within the spirit of the invention are desired to be protected.

The invention claimed is:

1. An electrochemical battery system, comprising:

a plurality of first electrochemical cells;

a memory in which command instructions are stored; and

a processor configured to execute the command instructions to (i) evaluate each of the plurality of first electrochemical cells, (ii) selectively connect a first of the plurality of first electrochemical cells to a power provider based upon the evaluation while selectively isolating a second of the plurality of first electrochemical cells from the power provider based upon the evaluation, (iii) identify an amount of current passed into the first of the plurality of first electrochemical cells while the second of the plurality of first electrochemical cells is isolated, and (iv) reset a 0% state of charge (SOC) threshold for the first of the plurality of first electrochemical cells based upon the amount of current passed into the first of the plurality of first electrochemical cells with the second of the plurality of first electrochemical cells isolated.

2. The electrochemical battery system of claim **1**, wherein the evaluation comprises identifying for each of the plurality of first electrochemical cells a respective state of charge (SOC).

3. The electrochemical battery system of claim **2**, wherein the processor is further configured to execute the command instructions to:

identify each of the plurality of first electrochemical cells with a SOC above a first SOC threshold and below a second SOC threshold; and

preferentially connect each of the identified plurality of first electrochemical cells to the power provider when the power provider is receiving power from the electrochemical battery system.

4. The electrochemical battery system of claim **3**, wherein the processor is further configured to execute the command instructions to:

identify each of the plurality of first electrochemical cells with a SOC below the first SOC threshold; and

preferentially connect each of the identified plurality of first electrochemical cells with a SOC below the first SOC threshold to the power provider when the power provider is providing power to the electrochemical battery system.

5. The electrochemical battery system of claim **1**, wherein the power provider is a second electrochemical cell.

6. The electrochemical battery system of claim **1**, wherein the power provider is a commercial power grid.

7. An electrochemical battery system, comprising:

a first electrochemical cell;

a second electrochemical cell;

a memory in which command instructions are stored; and

a processor configured to execute the command instructions to (i) evaluate the first electrochemical cell and the second electrochemical cell, (ii) compare a present state of charge (SOC) of the first electrochemical cell with a present SOC of the second electrochemical cell, (iii) preferentially connect the first electrochemical cell to a power provider based upon the comparison while selectively isolating the second electrochemical cell from the power provider based upon the comparison, (iv) identify an amount of current passed into the power provider from the first electrochemical cell, and (v) credit a pecuniary account based upon the amount of current passed into the power provider from the first electrochemical cell.

8. The electrochemical battery system of claim **7**, wherein the evaluation comprises identifying a respective state of charge (SOC) for the first electrochemical cell and for the second electrochemical cell.

9. The electrochemical battery system of claim **8**, wherein the processor is further configured to execute the command instructions to:

evaluate the SOC of the first electrochemical cell and the SOC of the second electrochemical cell with respect to a predetermined threshold;

identify an amount of current passed into the first electrochemical cell from the power provider; and

identify a 0% SOC threshold for the first electrochemical cell based upon the amount of current passed into the first electrochemical cell.

10. The electrochemical battery system of claim **8**, wherein the processor is further configured to execute the command instructions to:

determine that the SOC of the first electrochemical cell is above a first SOC threshold and below a second SOC threshold; and

preferentially connect the first electrochemical cell to the power provider based upon the determination.

11. The electrochemical battery system of claim **8**, wherein the processor is further configured to execute the command instructions to:

selectively connect the second electrochemical cell to the power provider and selectively disconnect the first electrochemical cell from the power provider after a charge has been transferred from the first electrochemical cell to the power provider.

12. The electrochemical battery system of claim **7**, wherein:

the power provider is a Vehicle-to-Grid network.

13. The electrochemical battery system of claim **7**, wherein the processor is further configured to execute the command instructions to selectively connect the first electrochemical cell to the power provider to pass power to the power provider based upon power demand on the power provider.

14. The electrochemical battery system of claim **7**, wherein the processor is further configured to execute the command instructions to selectively connect the first electrochemical cell to the power provider to pass power to the power provider based upon time of day.

15. An electrochemical battery system, comprising:

a first electrochemical cell;

a second electrochemical cell;

a memory in which command instructions are stored; and

a processor configured to execute the command instructions to (i) evaluate the first electrochemical cell and the second electrochemical cell, (ii) determine a present state of charge (SOC) of the first electrochemical cell and a present SOC of the second electrochemical cell, (iii) compare the present SOC of the first electrochemical cell with the present SOC of the second electrochemical cell, and (iv) preferentially connect the first electrochemical cell to a power provider based upon the comparison while selectively isolating the second electrochemical cell from the power provider based upon the comparison.

16. The electrochemical battery system of claim **15**, wherein the processor is further configured to execute the command instructions to:

identify when the present SOC of the first electrochemical cell and the present SOC of the second electrochemical cell are above a first SOC threshold and below a second SOC threshold; and

preferentially connect the first electrochemical cell to the power provider based upon the comparison and the identification while selectively isolating the second electrochemical cell from the power provider based upon the comparison and the identification when the power provider is receiving power from the electrochemical battery system.

17. The electrochemical battery system of claim **16**, wherein the processor is further configured to execute the command instructions to:

identify when the present SOC of the first electrochemical cell and the present SOC of the second electrochemical cell are below the first SOC threshold; and

preferentially connect the first electrochemical cell to the power provider based upon the comparison and the identification while selectively isolating the second electrochemical cell from the power provider based upon the comparison and the identification when the power provider is providing power to the electrochemical battery system.

18. The electrochemical battery system of claim **15**, wherein the power provider is a second electrochemical cell.

19. The electrochemical battery system of claim **15**, wherein the power provider is a commercial power grid.

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