United States Patent Application Publication	20250260250
Kind Code	A1
Publication Date	August 14, 2025
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METHOD FOR OPERATING AN ENERGY STORAGE SYSTEM, AN ENERGY STORAGE RACK, OR AN ENERGY STORAGE MODULE

Abstract

a method for operating an energy storage module having multiple energy storage cells by: a) obtaining a cell lifetime for at least one energy storage cell, wherein the cell lifetime depends at least on thermal effects and voltage effects; and for each energy storage cell: b) determining a thermal cell aging factor, that is indicative of an aging process of the energy storage cell due to thermal effects; c) determining a voltage offset required to obtain the lifetime obtained in step a); and d) activating balancing of the respective energy storage cell based on the voltage offset obtained in step c).

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Family ID: **1000008489980**

Appl. No.: **19/048495**

Filed: **February 07, 2025**

Foreign Application Priority Data

DE	102024103577.3	Feb. 08, 2024
DE	102024104161.7	Feb. 14, 2024

Publication Classification

Int. Cl.: **H02J7/00** (20060101); **G01R31/374** (20190101); **G01R31/392** (20190101); **H01M10/42** (20060101); **H01M10/48** (20060101)

U.S. Cl.:

CPC **H02J7/005** (20200101); **G01R31/374** (20190101); **G01R31/392** (20190101); **H01M10/425** (20130101); **H01M10/486** (20130101); **H02J7/0048** (20200101); **H02J7/007182** (20200101); H01M2010/4271 (20130101)

Background/Summary

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims the benefit of German Patent Application Number 10 2024 104 161.7 filed on Feb. 14, 2024 and German Patent Application Number 10 2024 103 577.3 filed on Feb. 8, 2024, the entire disclosures of which are incorporated herein by way of reference.

FIELD OF THE INVENTION

[0002] The invention relates to a method for operating an energy storage system, an energy storage rack, or an energy storage module with multiple energy storage cells.

BACKGROUND OF THE INVENTION

[0003] Energy storage systems that include multiple energy storage cells typically require some sort of management of cell voltages. This may have different causes, such as variations in manufacturing or—over time—degradation of the cells depending on environmental conditions or usage conditions, for example.

[0004] Energy storage cells as described herein may be classified into three varieties: batteries, capacitors and ultracapacitors (sometimes also called supercapacitors).

[0005] The term “battery” as used herein is an energy storage cell that stores electrical energy exclusively by electrochemical redox reaction. This typically includes primary batteries that can only be discharged. However, as used herein, the term “battery” exclusively means secondary battery, i.e., a battery that may be charged and discharged.

[0006] The term “capacitor” as used herein is an energy storage cell that stores electrical energy electrostatically.

[0007] The term “ultracapacitor” as used herein is a special kind of capacitor and may be further distinguished into a double-layer capacitor (DLC) that stores energy electrostatically using a Helmholtz double layer, a pseudocapacitor that stores electrical energy electrochemically by Faradaic electron charge-transfer such as intercalation or electrosorption, or a hybrid capacitor that uses both mechanisms of the DLC and the pseudocapacitor.

[0008] Energy storage modules based on ultracapacitors are becoming more and more popular in various applications. Applications are, for example, grid stabilization, high-power power supplies, and off-shore automation. Ultracapacitors can be easily charged and are able to provide large peak powers within a short amount of time, which is ideal for these applications.

[0009] A significant factor determining the lifetime of the energy storage modules is the aging of the individual energy storage cells within that module. Temperature variations have a noticeable impact on the aging process and as a result on the lifetime of the energy storage cells. Generally, the lifetime of the energy storage module is determined by the energy storage cell with the lowest lifetime.

[0010] Thermal management within the energy storage modules is therefore an important topic in this field and has been addressed in different ways.

[0011] German patent application 10 2023 111 690.8 discloses a support structure for an energy storage module with multiple energy storage cells. The structure is designed to allow for a more uniform temperature distribution between the energy storage cells, thereby allowing roughly the same aging conditions. This is achieved by special arrangement of ventilations holes in the support structure.

[0012] German patent application 10 2023 117 427.4 discloses an energy storage module with

temperature based cell voltage control for high-power applications. The controller measures the temperature of a cell of the energy storage module and upon certain thresholds adjusts the respective cell voltage with the goal of mitigating temperature effects on the lifetime of the cells.
[0013] Unpublished German patent application 10 2024 102 852.1 discloses an abnormal cell detection and balancing method for compensating the abnormally behaving cells.
[0014] Weighted balancing is typically applied to keep the voltage imbalance between different cells within an energy storage system as small as possible. Balancing methods are well-known and reference is made to the following documents: [0015] US 2013/0 278 227 A1 [0016] CN 103 891 087 A [0017] CN 105 471 010 A [0018] WO 2014/057 088 A2 [0019] CN 110 768 237 A [0020] CN 107 800 292 A [0021] CN 107 257 147 A [0022] U.S. Pat. No. 9,525,298 B1 [0023] CN 104 410 132 A [0024] CN 101 414 759 B [0025] CN 103 066 664 B
SUMMARY OF THE INVENTION
[0026] It is an object of the invention to improve energy storage systems, preferably regarding lifetime and energy content.
[0027] The object may be achieved by the subject-matter of one or more embodiments described herein.
[0028] The invention provides a method for operating an energy storage system, an energy storage rack, or an energy storage module having multiple energy storage cells, preferably in order to mitigate thermal aging effects on the energy storage cells, the method comprising: [0029] a) obtaining a cell lifetime for at least one each energy storage cell, wherein the cell lifetime depends at least on thermal effects and voltage effects; and [0030] for each energy storage cell: [0031] b) determining a thermal cell aging factor, that is indicative of an aging process of the energy storage cell due to thermal effects; [0032] c) determining a voltage offset required to obtain the lifetime obtained in step a); and [0033] d) activating balancing of the respective energy storage cell based on the voltage offset obtained in step c).
[0034] Preferably, in step a) obtaining the cell lifetime involves determining a cell temperature of at least one energy storage cell and determining the cell lifetime based on the cell temperature.
[0035] Preferably, determining the cell lifetime involves determining at least one cell aging factor, preferably the thermal cell aging factor and/or a voltage cell aging coefficient, and the cell lifetime is determined based on each cell aging factor.
[0036] Preferably, the cell lifetime is that of the coldest energy storage cell.
[0037] Preferably, determining a cell temperature involves measuring a temperature with temperature sensors arranged at distributed measuring points within the energy storage module, calculating a temperature distribution within the energy storage module based on the measurements, and selecting a temperature value from the temperature distribution at the location of the energy storage cell within the energy storage module as the cell temperature.
[0038] Preferably, the amount of distributed measuring points is smaller than the number of energy storage cells, preferably smaller than half the number of energy storage cells.
[0039] Preferably, in step c) determining the offset voltage involves determining a voltage cell aging factor that is indicative of an aging process of the energy storage cell due to voltage effects.
[0040] Preferably, in step d) balancing is switched on, if the voltage offset of step c) exceeds a predetermined threshold.
[0041] Preferably, the method further comprises the step: [0042] e) if the energy storage module is discharging and supplying power, the energy storage module is discharged until one energy storage cell reaches 0% state of charge (SoC) or reaches a cell voltage of 0 V; or the energy storage module is discharged until the energy storage module reaches half the nominal voltage, quarter the nominal voltage, or 10% the nominal voltage.
[0043] The invention provides a management system for an energy storage system, for an energy storage rack, or for an energy storage module that is configured for storing electrical energy and comprises a plurality of energy storage cells, preferably ultracapacitors, wherein the management

system is configured to carry out a preferred method.

[0044] The invention provides an energy storage system, an energy storage rack, or an energy storage module comprising a plurality of energy storage cells, preferably ultracapacitors, and the management system.

[0045] The invention provides a computer program comprising instructions that, upon execution by a management system, cause the management system to carry out a preferred method.

[0046] The invention provides a computer-readable storage medium comprising the computer program.

[0047] Advantageous effects and other features of this idea will be described below. It should be noted that not all advantages need to be present at the same time or to the same degree.

[0048] Thermal mitigation is an important part of energy storage management. Here, the idea is to implement thermal balancing. During thermal balancing, the cell voltage is lowered on higher temperature cells. The goal is to equalize the lifetime of all energy storage cells in a system. In contrast, the current approach only balances the cell voltages equally and does not consider other parameters that can affect cell lifetime.

[0049] Uneven temperatures of the energy storage cells are typically caused by the mechanical design of the energy storage module, where in particular the energy storage cells in the center of the energy storage module have less surface area to the outside than the energy storage cells in outer positions. Thus, heat can usually escape much more easily from the outer energy storage cells compared to those near the center. In some cases the heat can get trapped due to relying on natural convection cooling.

[0050] Another possible source of uneven cell temperatures could be the balancing circuit. Furthermore, the rack design might also impact the temperature distribution of the energy storage cells.

[0051] The current approach of the cell voltage balancing algorithm is to keep cell voltages equal within one rack/system. This means that lifetime differences due to the temperature differences can be expected. Assuming that a module lifetime is generally defined by the most aged cell, then the module is typically replaced when the first cell reaches the end of life. Therefore, plenty of cell lifetime is wasted due to the uneven aging of the cells.

[0052] As of yet, this uneven aging was addressed by oversizing the system, when a certain expected lifetime was needed. This was done by having more energy storage modules in series which in turn allows a decrease of the average cell voltage in the system.

[0053] The lifetime of energy storage cells, and in particular of ultracapacitors, is mainly affected by cell temperature and cell voltage. The effects of both can be described via aging factors (AF) which are the relative change multiplier in expected lifetime.

[0054] The thermal cell aging factor (AF.sub.T) is based on a modified Arrhenius equation. In most cases, the equation can be generalized as doubling the reaction rate for every 10° C. increase in temperature T, if temperature is below a temperature threshold T.sub.S, and doubling the reaction rate for every 5° C. increase in temperature above the temperature threshold:

[00001] $$AF_T = 2^{\frac{T_{\mathrm{cell}} - T_S}{T_D}}, \quad (1)$$

[0055] where T.sub.cell is the cell temperature, T.sub.S is the temperature threshold, and T.sub.D is the doubling temperature (i.e. 10° C. or 5° C.) as described above. The temperature threshold depends on the type of energy storage cell and can be obtained from experiment.

[0056] The voltage cell aging factor (AF.sub.V) can be modeled with a similar form to the Arrhenius equation, but uses two different voltage ranges. At voltages below a voltage threshold, the reaction rate is doubled for a given voltage increase. At voltages above the voltage threshold, the reaction rate is doubled for every half of the given voltage increase:

[00002] $$AF_V = 2^{\frac{V_{\mathrm{cell}} - V_S}{V_D}}, \quad (2)$$

[0057] where V.sub.cell is the cell voltage, Vs is the voltage threshold, and V.sub.D is the doubling

voltage (typically less than a tenth of the cell voltage). The reason for this is that as the voltage is increased, not only do the rates of side reactions from impurities increase, but also the number of possible side reactions increase. The voltage threshold and the voltage increase depend on the type of energy storage cell and can be obtained from experiment.
[0058] The cell lifetime (LT.sub.cell) can be estimated from a base level lifetime (LT.sub.B) at well-defined conditions, where the base lifetime is again determined by experiment:
[00003] $$LT_{cell} = \frac{LT_B}{AF_T \text{ .Math. } AF_V} \quad (3)$$
[0059] Thermal balancing is the methodology disclosed herein to control the individual cell voltage based on the cell temperature with the goal of aging all energy storage cells as evenly as possible inside the module. As stated previously, both the cell voltage and the cell temperature contribute to the aging of the capacitor cells. This means that lowering the cell temperature or the cell voltage can be used to increase the total usable cell lifetime. Since the cell temperature is typically given by the circumstances of the operation and may vary accordingly, changing the cell voltage can be used to adjust the aging of the respective energy storage cell. In particular, lowering the cell voltage of energy storage cells that experience a higher cell temperature allows equalizing the aging of the energy storage cells in the module.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0060] Embodiments of the invention are described in more detail with reference to the accompanying schematic drawings that are listed below
[0061] FIG. **1** depicts an embodiment of an energy storage system;
[0062] FIG. **2** depicts an embodiment of an energy storage module;
[0063] FIG. **3** depicts an embodiment of a method for operating the energy storage system;
[0064] FIG. **4** depicts a voltage-lifetime diagram;
[0065] FIG. **5** depicts an energy-lifetime diagram; and
[0066] FIG. **6** depicts an energy gain-lifetime diagram.
DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS
[0067] Referring to FIG. **1** an embodiment of an energy storage system **10** is schematically depicted. The energy storage system **10** may be used for grid stabilization, in particular for mitigating the effects of power sags or power disruptions, or for providing peak loads during ramp-up of power intensive machinery or equipment.
[0068] The energy storage system **10** may include one or more energy storage racks **12**. The energy storage racks **12** are suitably connected according to the application. The energy storage racks **12** are connected in parallel or in series depending on the application.
[0069] Each energy storage rack **12** includes a rack controller **14** and a plurality of energy storage modules **16**. The rack controller **14** is configured to control the energy storage modules **16** that are installed in the respective energy storage rack **12**. A plurality of rack controllers **14** may operationally form a system controller by communicating with each other. It is also possible for the energy storage system **10** to include a separate system controller (not shown) that communicates with and controls the energy storage racks **12** via the rack controllers **14**.
[0070] Referring to FIG. **2** the energy storage module **16** is described in more detail. The energy storage module **16** comprises a plurality of energy storage cells **18** and a module controller **20**. A first and second terminal **22**, **24** are formed on the energy storage module **16**, which allow electrical connection to other energy storage modules **16**, preferably of the same energy storage rack **12**.
[0071] The module controller **20** is configured to control general operation of the energy storage module **16**, in particular charging and discharging of the energy storage cells **18**. Furthermore, the module controller **20** is operatively coupled to each individual cell to allow controlling a cell

voltage V.sub.cell of each individual energy storage cell **18**. In particular the module controller **20** allows decreasing of the cell voltage V.sub.cell during balancing, preferably by discharging the respective energy storage cell **18** using a balancing circuit. In its simplest form the balancing circuit involves a switch, e.g., a transistor, and a balancing resistor.

[0072] As indicated in FIG. **2**, the innermost energy storage cells **18** have a higher temperature than more outer located energy storage cells **18**. It is also indicated that energy storage cells **18** closer to the module controller **20** may experience a higher cell temperature.

[0073] Each module controller **20** may be operatively coupled to the rack controller **14**. In some embodiments, two or more module controllers **20** may collectively form the rack controller **14** without a separate physical component present. It is also possible, that each module controller **20** is integrated into the rack controller **14** as a physical and/or software component thereof.

[0074] The rack controller **14**, the system controller, and the module controller **20**, as the case may be, may be collectively referred to as a management system **26**.

[0075] The energy storage module **16** further comprises a plurality of thermal sensors **28** that are distributed within the energy storage module **16**. The thermal sensors **28** measure the local temperature in their vicinity and are coupled to the management system **26**, which processes these data.

[0076] Referring to FIG. **3**, an embodiment of a method for operating the energy storage system **10** is described in more detail.

[0077] In a lifetime calculation step S**31**, the management system **26** determines the cell lifetime of the coldest energy storage cell **18**.

[0078] The management system **26** receives the temperatures measured by the temperature sensors **28**. The management system **26** determines a temperature distribution from the measured temperatures. It is assumed that the energy storage cells **18** have a cell temperature T.sub.cell that corresponds to the temperature given by the temperature distribution at the respective location of the energy storage cell **18**. The temperature distribution can be obtained based on simulation data that were generated by performing thermal simulations of the energy storage module **16** beforehand. These simulation data also help to identify the ideal locations for the temperature sensors **28**. The thermal simulations may involve determining a temperature gradient and based on the gradient determining the cell temperature T.sub.cell. It is also possible to determine the cell temperature T.sub.cell based on a look-up-table that is obtained from the simulation data. It should be noted that it is also possible to equip each and every energy storage cell **18** with a temperature sensor **28**.

[0079] Based on the temperature distribution, the management system **26** identifies the coldest energy storage cell **18** and its cell temperature T.sub.cell. Furthermore, the management system **26** determines the cell voltage V.sub.cell of that energy storage cell **18**. The management system **26** determines the thermal and voltage cell aging factors AF.sub.T and AF.sub.V according to equation (1) and (2), respectively. Next, the management system **26** determines the cell lifetime LT.sub.cell according to equation (3).

[0080] It should be noted that the cell lifetime LT.sub.cell need not be determined in exactly this manner. Other cell lifetime estimation models may be used, as long as the respective model includes a temperature dependence and a voltage dependence of the cell lifetime.

[0081] In a thermal aging factor calculation step S**32**, the management system **26** determines the thermal cell aging factors AF.sub.T of the remaining energy storage cells **18**. It should be noted that it is possible to carry out the steps S**31** and S**32** simultaneously.

[0082] In a target voltage aging calculation step S**33**, the management system **26** determines the voltage cell aging factors AF.sub.V of the remaining energy storage cells **18** such that these energy storage cells **18** have the same estimated cell lifetime LT.sub.cell as the coldest energy storage cell **18**.

[0083] In a voltage offset calculation step S**34**, the management system **26** determines the voltage offset V.sub.off for each energy storage cell **18**. The voltage offset V.sub.off is determined such that all energy storage cells **18** have the same estimated cell lifetime LT.sub.cell as the coldest energy storage cell **18**. The voltage offset V.sub.off is determined based on equation (2) and the current cell voltage V.sub.cell of the respective energy storage cell **18**.

[0084] It should be noted that the steps S**33** and S**34** may also be combined into a single calculation step.

[0085] In a balancing step S**35**, the management system **26** activates balancing for the energy storage cells **18** and applies the respective voltage offsets V.sub.off. The balancing algorithm, e.g., weighted balancing, will then adjust the cell voltage V.sub.cell accordingly.

[0086] The management system **26** may also apply a threshold voltage V.sub.thresh, such that only for energy storage cells **18** that require an absolute voltage offset V.sub.off greater than the threshold voltage V.sub.thresh, i.e. |V.sub.off|>V.sub.thresh, balancing is activated. In a case, where the management system **26** can perform balancing only by reducing the cell voltage V.sub.cell, balancing is only activated for energy storage cells **18** that require a decrease in the cell voltage V.sub.cell to achieve the desired estimated cell lifetime LT.sub.cell.

[0087] Referring to FIG. **4** through FIG. **6**, simulation results of an energy storage module **16** that employs the previously described method are presented to show the effectiveness of the method.

[0088] FIG. **4** depicts a module lifetime diagram of the energy storage module **16**, where the x-axis is the module voltage V.sub.mod and the y-axis is the module lifetime LT.sub.mod.

[0089] The left curve **30** shows the uncompensated case, where all energy storage cells **18** in the energy storage module **16** have the same cell voltage V.sub.cell.

[0090] The right curve **32** shows the compensated case, where the energy storage cells **18** are balanced according to the disclosed thermal balancing method, i.e., the cell voltages V.sub.cell are compensated by voltage offsets V.sub.off to have the same cell lifetime LT.sub.cell. Surprisingly, the thermal balancing method allows the module voltage V.sub.mod to be higher given the lifetime as in the uncompensated case. The simulations have shown that the voltage offset V.sub.off to achieve the same cell lifetimes LT.sub.cell typically does not exceed 200 mV.

[0091] FIG. **5** depicts a module lifetime diagram of the energy storage module **16**, where the x-axis is the module energy E.sub.mod (typically Wh) and the y-axis is the module lifetime LT.sub.mod.

[0092] The left curve **34** shows the uncompensated case, where all energy storage cells **18** in the energy storage module **16** have the same cell voltage V.sub.cell.

[0093] The right curve **36** shows the thermal balancing case according to the invention. As the thermal balancing allows an increase in the module voltage V.sub.mod, the usable module energy can also be increased. Usable module energy is defined here as discharging the energy storage module **16** from the fully charged state down to half-nominal voltage.

[0094] FIG. **6** depicts a module lifetime diagram of the energy storage module **16**, where the x-axis is the module energy gained compared to the uncompensated case and the y-axis is the module target lifetime LT.sub.mod.

[0095] The energy gain is at least 6% compared to the uncompensated case and allows an energy gain of 15.5% for a module design lifetime of 20 years. This energy gain due to thermal balancing is rather significant.

[0096] The systems and devices described herein may include a controller or a computing device comprising a processing unit and a memory which has stored therein computer-executable instructions for implementing the processes described herein. The processing unit may comprise any suitable devices configured to cause a series of steps to be performed so as to implement the method such that instructions, when executed by the computing device or other programmable apparatus, may cause the functions/acts/steps specified in the methods described herein to be executed. The processing unit may comprise, for example, any type of general-purpose microprocessor or microcontroller, a digital signal processing (DSP) processor, a central processing unit (CPU), an integrated circuit, a field programmable gate array (FPGA), a reconfigurable

processor, other suitably programmed or programmable logic circuits, or any combination thereof.
[0097] The memory may be any suitable known or other machine-readable storage medium. The memory may comprise non-transitory computer readable storage medium such as, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. The memory may include a suitable combination of any type of computer memory that is located either internally or externally to the device such as, for example, random-access memory (RAM), read-only memory (ROM), compact disc read-only memory (CDROM), electro-optical memory, magneto-optical memory, erasable programmable read-only memory (EPROM), and electrically-erasable programmable read-only memory (EEPROM), Ferroelectric RAM (FRAM) or the like. The memory may comprise any storage means (e.g., devices) suitable for retrievably storing the computer-executable instructions executable by processing unit.
[0098] The methods and systems described herein may be implemented in a high-level procedural or object-oriented programming or scripting language, or a combination thereof, to communicate with or assist in the operation of the controller or computing device. Alternatively, the methods and systems described herein may be implemented in assembly or machine language. The language may be a compiled or interpreted language. Program code for implementing the methods and systems described herein may be stored on the storage media or the device, for example a ROM, a magnetic disk, an optical disc, a flash drive, or any other suitable storage media or device. The program code may be readable by a general or special-purpose programmable computer for configuring and operating the computer when the storage media or device is read by the computer to perform the procedures described herein.
[0099] Computer-executable instructions may be in many forms, including modules, executed by one or more computers or other devices. Generally, modules include routines, programs, objects, components, data structures, etc., that perform particular tasks or implement particular abstract data types. Typically, the functionality of the modules may be combined or distributed as desired in various embodiments.
[0100] It will be appreciated that the systems and devices and components thereof may utilize communication through any of various network protocols such as TCP/IP, Ethernet, FTP, HTTP and the like, and/or through various wireless communication technologies such as GSM, CDMA, Wi-Fi, and WiMAX, is and the various computing devices described herein may be configured to communicate using any of these network protocols or technologies.
[0101] While at least one exemplary embodiment of the present invention(s) is disclosed herein, it should be understood that modifications, substitutions and alternatives may be apparent to one of ordinary skill in the art and can be made without departing from the scope of this disclosure. This disclosure is intended to cover any adaptations or variations of the exemplary embodiment(s). In addition, in this disclosure, the terms “comprise” or “comprising” do not exclude other elements or steps, the terms “a” or “one” do not exclude a plural number, and the term “or” means either or both. Furthermore, characteristics or steps which have been described may also be used in combination with other characteristics or steps and in any order unless the disclosure or context suggests otherwise. This disclosure hereby incorporates by reference the complete disclosure of any patent or application from which it claims benefit or priority.
LIST OF REFERENCE SIGNS
[0102] **10** energy storage system [0103] **12** energy storage rack [0104] **14** rack controller [0105] **16** energy storage module [0106] **18** energy storage cell [0107] **20** module controller [0108] **22** first terminal [0109] **24** second terminal [0110] **26** management system [0111] **28** temperature sensor [0112] **30** left curve [0113] **32** right curve [0114] **34** left curve [0115] **36** right curve

Claims

1. A method for operating an energy storage system, an energy storage rack, or an energy storage module having multiple energy storage cells, the method comprising: a) obtaining a cell lifetime for at least one energy storage cell, wherein the cell lifetime depends at least on thermal effects and voltage effects; and for each energy storage cell: b) determining a thermal cell aging factor indicative of an aging process of the energy storage cell due to thermal effects; c) determining a voltage offset required to obtain the cell lifetime obtained in step a); and d) activating balancing of the energy storage cell based on the voltage offset obtained in step c).
2. The method according to claim 1, wherein step a) comprises determining a cell temperature of the at least one energy storage cell and determining the cell lifetime based on the cell temperature.
3. The method according to claim 2, wherein determining the cell lifetime comprises determining at least one cell aging factor and the cell lifetime is determined based on each cell aging factor.
4. The method according to claim 1, wherein the cell lifetime is based on a coldest energy storage cell.
5. The method according to claim 1, wherein determining a cell temperature comprises measuring a temperature to obtain measurements with temperature sensors arranged at distributed measuring points within the energy storage module, calculating a temperature distribution within the energy storage module based on the measurements, and selecting a temperature value from the temperature distribution at a location of the energy storage cell within the energy storage module as the cell temperature.
6. The method according to claim 5, wherein an amount of distributed measuring points is smaller than a number of energy storage cells.
7. The method according to claim 1, wherein step c) comprises determining a voltage cell aging factor indicative of an aging process of the energy storage cell due to voltage effects.
8. The method according to claim 1, wherein during step d) balancing is switched on, when the voltage offset of step c) exceeds a predetermined threshold.
9. The method according to claim 1 further comprising: e) when the energy storage module is discharging and supplying power, the energy storage module is discharged until one energy storage cell reaches 0% state of charge (SoC) or reaches a cell voltage of 0 V; or when the energy storage module is discharging and supplying power, the energy storage module is discharged until the energy storage module reaches half a nominal voltage, quarter a nominal voltage, or 10% a nominal voltage.
10. A management system for an energy storage system, an energy storage rack, or an energy storage module that is configured for storing electrical energy, the management system comprising: a plurality of energy storage cells, wherein the management system is configured to carry out the method according to claim 1.
11. An energy storage system, an energy storage rack, or an energy storage module comprising: a plurality of energy storage cells, and a management system configured to carry out the method according to claim 1.
12. A non-transitory computer readable medium comprising a computer program comprising instructions that, upon execution by a management system with a processor, cause the management system to carry out the method according to claim 1.