

**Methods and systems for lifetime management of battery pack by creating a digital
copy**

CROSS REFERENCE TO RELATED APPLICATION

This application is based on and derives the benefit of Indian Provisional Application 201841042531 as filed on 12th November 2018, the contents of which are incorporated herein by reference.

TECHNICAL FIELD

[001] Embodiments disclosed herein relate to management of battery packs and more particularly to managing, monitoring and tracking battery packs by creating digital copies of the battery packs.

BACKGROUND

[002] A battery pack comprises modules such as battery cells, sensors for temperature, voltage, current, location sensing means, accelerometer, electronic control systems for battery management, telemetry and built-in-in modem with remote server systems for tracking and monitoring, and so on.

[003] Once the battery pack has been manufactured and deployed for use in field application, there could be performance related alerts and issues received by a server system to which the battery pack communicates. Ability to understand configuration of a given battery pack and identify which component is causing issues and how it tested during manufacturing can be critical.

[004] Further, existing solutions for manufacturing automation may not provide a hierarchical configuration to represent the battery pack and also with some of the components being 'active' and addressable remotely.

SUMMARY

[004a] According to a first aspect, there is provided a battery pack management system including: a data storage, a battery pack assembly line, and a digital controller, wherein the digital controller is configured for: creating at least one digital copy of at least one battery pack, wherein the digital copy is stored in the data storage; and monitoring, tracing and managing the at least one battery pack using the created at least one digital copy after deploying the at least one battery pack in at least one field, wherein the battery pack assembly line is configured for assembling at least one battery pack using at least one component of a plurality of components, which further includes: performing a plurality of first level of tests on the plurality of components to be used for assembling the at least one battery pack using at least one threshold defined by the digital controller, wherein the plurality

of first level of tests include assembly line tests and high rate discharge tests; receiving at least one indication from the digital controller upon communicating results of the plurality of first level of tests to the digital controller, wherein the indication includes information about the at least one component selected by the digital controller for assembling the at least one battery pack and at least one rule for assembling the at least one battery pack; and assembling the at least one battery pack using the at least one selected component based on the at least one indication received from the digital controller, wherein the digital controller is further configured for: configuring the at least one battery pack to operate in an field mode; performing a plurality of third level of tests on the at least one battery pack based on at least one alert condition received from the at least one battery pack, wherein the plurality of third level of tests include field diagnostic tests; performing at least one correctional procedure on the at least one battery pack based on a result of the plurality of third level of tests; and updating the at least one digital copy corresponding to the at least one battery pack based on the performed correctional procedure.

[004b] According to a second aspect, there is provided a method for lifetime management of battery packs, the method including: creating, by a digital controller, at least one digital copy of at least one battery pack, wherein the digital copy is stored in a data storage; monitoring, tracing and managing, by the digital controller, the at least one battery pack using the created at least one digital copy after deploying the at least one battery pack in at least one field; assembling, by a battery pack assembly line, at least one battery pack using at least one component of a plurality of components; performing, by the battery pack assembly line, a plurality of first level of tests on the plurality of components to be used for assembling the at least one battery pack using at least one threshold defined by the digital controller, wherein the plurality of first level of tests include assembly line tests and high rate discharge tests; receiving, by the battery pack assembly line, at least one indication from the digital controller upon communicating results of the plurality of first level of tests to the digital controller, wherein the indication includes information about the at least one component selected by the digital controller for assembling the at least one battery pack and at least one rule for assembling the at least one battery pack; and assembling, by the battery pack assembly line, the at least one battery pack using the at least one selected component based on the at least one indication received from the digital controller, wherein monitoring, tracing and managing, by the digital controller, the at least one battery pack includes: configuring the at least one battery pack to operate in an field mode; performing a plurality of third level of tests on the at least one battery pack based on at least one alert condition received from the at least one battery pack, wherein the plurality of third level of tests include field diagnostic tests; performing at least one correctional procedure on the at least one battery pack based on a result of the plurality of third level of tests; and updating the at least one digital copy corresponding to the at least one battery pack based on the performed correctional procedure.

[005] Embodiments herein disclose methods and systems for creating at least one digital copy of at least one battery pack, wherein the at least one digital copy includes at least one of configuration information of the at least one battery pack and associated components, results of tests performed on the at least one battery pack and the associated components at various stages, unique identifiers of the at least one battery pack and the associated components, thresholds used for performing the tests and rules defined for assembling the at least one battery pack.

[006] Embodiments herein disclose methods and systems for monitoring, tracing and managing the at least one battery pack using the at least one digital copy and data received from the at least one battery pack when the at least one digital copy is deployed in at least one field.

[007] These and other aspects and embodiments disclosed herein will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings. It should be understood, however, that the following descriptions, while indicating at least one embodiment and numerous specific details thereof, are given by way of illustration and not of limitation. Many changes and modifications may be made within the scope of the embodiments herein without departing from the spirit thereof, and the embodiments herein include all such modifications.

BRIEF DESCRIPTION OF FIGURES

[008] Embodiments herein are illustrated in the accompanying drawings, throughout which like reference letters indicate corresponding parts in the various figures. The embodiments herein will be better understood from the following description with reference to the drawings, in which:

[009] FIG. 1 depicts a battery pack management system, according to embodiments as disclosed herein;

[0010] FIGs. 2a and 2b depict a battery pack management system, according to embodiments as disclosed herein;

[0011] FIG. 3 is an example diagram illustrating various modules of the digital controller for creating the digital copy of the battery pack and managing the battery pack when the battery pack is deployed in the at least one field, according to embodiments as disclosed herein; and

[0012] FIG. 4 is a flow diagram illustrating a method for lifetime management of the at least one battery pack, according to embodiments as disclosed herein.

DETAILED DESCRIPTION

[0013] The embodiments herein and the various features and advantageous details thereof are explained more fully with reference to the non-limiting embodiments that are illustrated in the accompanying drawings and detailed in the following description. Descriptions of well-known components and processing techniques are omitted so as to not unnecessarily obscure the embodiments herein. The examples used herein are intended merely to facilitate an understanding of ways in which the embodiments herein may be practiced and to further enable those of skill in the art to practice the embodiments herein. Accordingly, the examples should not be construed as limiting the scope of the embodiments herein.

[0014] Embodiments herein disclose methods and systems for lifetime management of at least one battery pack by creating at least one digital copy of the at least one battery pack.

[0015] Embodiments herein disclose methods and systems for creating the at least one digital copy of the at least one battery pack based on at least one of configuration information of the at least one battery pack and associated components, results of tests performed on the at least one battery pack and the associated components at various stages, thresholds used for performing the tests, and rules defined for assembling the at least one battery pack and unique identifiers of the at least one battery pack and associated components.

[0016] Embodiments herein disclose methods and systems for monitoring, tracing and managing the at least one battery pack that is deployed in at least one field using data received from the at least one battery pack and the associated at least one digital copy.

[0017] Referring now to the drawings, and more particularly to FIGS. 1 through 4, where similar reference characters denote corresponding features consistently throughout the figures, there are shown embodiments.

[0018] FIG. 1 depicts a battery pack 100, according to embodiments as disclosed herein. The battery pack 100 referred herein can be present in any location such as, but not limited to, a charging station or the like. The battery pack 102 can also be used in fields such as, but not limited to, in a vehicle, a power supply and so on. Example of the vehicle can be, but not limited to, an electric vehicle, an autonomous vehicle, a semiautonomous vehicle, a manually operated vehicle and so on. The battery pack 100 further includes a plurality of components. The battery pack 100 includes a plurality of modules 102, sensors 104, components controllers 106 and an on-board memory 108. The components
5 can communicate with each other using at least one of, a wired network (a Local Area Network (LAN), a Controller Area Network (CAN) network, a bus network, Ethernet and so on), a wireless network (a Wi-Fi network, a cellular network, a Wi-Fi Hotspot, Bluetooth, Zigbee and so on) and so on.

[0019] Each module 102 can comprise of a plurality of battery cells 102a.
15 The module 102 can be removed from the battery pack 100 and can be used in other battery pack. The sensor 104 can for sensing parameters such as, but not limited to, temperature, voltage, current, location and so on. The components controllers 106 can be printed circuit boards (PCBs) for controlling the modules 102 and the sensors 104. The components controller 106 can include at least one
20 of a battery management system (BMS) unit 106a, a system control unit (SCU) 106b, a telematics unit (TIU) 106c and so on. The BMS unit 106a can regulate the modules 102 and the associated battery cells. The SCU 106b can regulate functions of the sensors 104. The TIU 106c can be configured to establish a communication between the battery pack and external entities (such as
25 components of a battery pack management system 100 or the like) through a communication network. Examples of the communication network can be, but is not limited to, the Internet, a wired network, a wireless network (a Wi-Fi network, a cellular network, a Wi-Fi Hotspot, Bluetooth, Zigbee and so on) and so on. Embodiments herein use the term active components to refer to the sensors 104
30 and the components controllers 106 or any other component of the battery, which enable the battery pack and/or the associated components to operate

autonomously. The active components (104, 106) can interact with other active components and/or the external entities through the communication network. Further, the active components (104, 106) can be addressed remotely by the external entities. For example, the active components can be addressed by
5 changing configurations associated with the active components.

[0020] FIGs. 2a and 2b depict a battery pack management system 200, according to embodiments as disclosed herein. The battery pack management system 200 referred herein can be configured for lifetime management of a plurality of battery packs 100. The battery pack management system 200 includes
10 a battery pack assembly line 202, a digital controller 204 and data storage 206. The battery pack assembly line 202, the digital controller 204 and the data storage 206 can be operated for managing manufacturing/creation of the battery pack(s) 100 by creating digital copy(ies) of the battery pack(s) 100 as illustrated in FIG. 2a. The digital controller 204 and the data storage 206 can be operated for
15 monitoring, tracing and managing the battery packs when the battery pack(s) 100 is deployed in the at least one field as illustrated in FIG. 2b, wherein the battery pack(s) 100 may be connected with the digital controller 204.

[0021] The battery pack assembly line 202 can be connected with the digital controller 204 and the data storage 206 using at least one of a wired
20 network (a Local Area Network (LAN), a Controller Area Network (CAN) network, a bus network, Ethernet and so on), a wireless network (a Wi-Fi network, a cellular network, a Wi-Fi Hotspot, Bluetooth, Zigbee and so on) and so on. The digital controller 204 referred herein can be at least one server, wherein the server may be a standalone server or a server on a cloud. Further, the server
25 may be any kind of computing device such as those, but not limited to a personal computer, a notebook, a tablet, desktop computer, a laptop, a handheld device a mobile device, and so on. The digital controller 204 of the battery pack management system 200 can also be connected to a cloud platform via a gateway (not shown). The cloud computing platform/controller 204 can be connected to

user devices located in different geographical locations in order to provide requested information about the battery pack to users of the user devices.

[0022] The battery pack assembly line 202 can be configured to assembly the battery pack 100 by performing tests on the individual components that are to be used for assembling the battery pack 100. Embodiments herein use the terms such as “assembly tests”, “first level of tests” and so on interchangeably to refer to the tests performed by the battery pack assembly line 202 on the components individually. The assembly tests can be at least one of assembly line tests, high rate discharge tests and so on.

[0023] The battery pack assembly line 202 scans each battery cell of the plurality of battery cells 102a and classifies characteristics of the battery cells 102a. The characteristics can be at least one of capacity, resistance, voltage, accuracy ranges and so on. Based on the classified characteristics, the battery pack assembly line 202 groups the battery cells 102a to form/develop the modules 102. For example, consider that the modules are developed using 15 battery cells, wherein a first module 102 can comprise of battery cells 2, 4, 5 and 10-15 of having same characteristics and a second module 102 can comprise of battery cells 1, 3 and 6-10 of having same characteristics. After forming the modules 102, the battery pack assembly line 202 performs the assembly line tests on the components (at least one of the modules 102, the sensors 104, the component controllers 106 and so on) to ensure that there is no deviation in temperature and voltage. Further, the battery pack assembly line 202 performs the high rate discharge tests on the components of the battery pack 100 to ensure that the voltage deviation is not high. In an embodiment, the battery pack assembly line 202 performs the assembly tests based on thresholds defined by the digital controller 204. The thresholds can be defined based on specification/configuration information of the components.

[0024] The battery pack assembly line 202 communicates results of the assembly tests (the assembly line tests and the high discharge test) to the digital controller 204 and receives indications from the digital controller 204 to assemble

the battery pack 100. The indications can include information about the selected components (based on the results of the tests) that can be used for the assembling the battery pack 100 and rules for assembling the battery pack. Based on the indications received from the digital controller 204, the battery pack assembly line 5 202 can assemble the battery pack 100 by physically connecting the selected components. The battery pack assembly line 104 further creates a unique identifier (ID) map by mapping a unique ID of each component (used in assembling) with an ID of the battery pack 100. The battery pack assembly line 202 further communicates information about a completion of the assembling of 10 the battery pack 100 and the unique ID mapping (including unique IDs of the battery pack 100 and the associated components) to the digital controller 204.

[0025] The digital controller 204 includes at least one of a single processor, a plurality of processors, multiple homogenous cores, multiple heterogeneous cores, multiple Central Processing Unit (CPUs) of different kinds, 15 a microprocessor, Input/Output modules (I/O modules), a memory and so on. The digital controller 204 can be configured to create the digital copy of the battery pack 100.

[0026] On receiving the information about the completion of the assembling of the battery pack 100 from the battery pack assembly line 202, the 20 digital controller 204 performs a plurality of tests on the assembled battery pack 100. Embodiments herein use the terms such as “second level of tests”, “certification tests” and so on interchangeably to refer to the plurality of tests performed by the digital controller 204 on the assembled battery pack 100 and the associated components. Examples of the tests performed on the assembled battery 25 pack 100/the associated components can be, but not limited to, insulation tests, communication/TIU tests, current calibration tests, End of Line (EOL) tests and so on. Based on results of the second level of tests performed on the assembled battery pack 100, the digital controller 204 certifies an authenticity of the battery pack 100 to deploy into the field and creates the digital copy. The digital 30 controller 204 creates the digital copy using at least one of the results of the tests

performed by the assembly line 202, the unique ID map, the results of the plurality of tests performed on the assembled battery pack 100, the threshold and rules used for performing the tests and assembling the battery pack 100 respectively and so on. The digital controller 204 can be further configured to
5 store the digital copy of the battery pack in the data storage 206. Embodiments herein use the terms such as “digital copy”, “digital twin” and so on interchangeably to refer to data copy including virtual data/information about the battery pack 100 and each component of the battery pack 100.

[0027] The digital controller 204 can also be configured to monitor, track
10 and manage the battery pack 100 after creating the digital copy. For example, the digital controller 100 can track/monitor the battery pack 102 when the battery pack 100 is in storage or when the battery pack is in transit to reach a destination (in order to deploy in the at least one field) or when the battery pack 100 is deployed in the at least one field. The digital controller 204 can monitor, track and
15 manage the battery pack 100 based on at least one of continuous data, alert conditions and so on received from the battery pack 100 and the digital copy stored corresponding to the battery pack 100.

[0028] The data storage 206 can store data, such as the digital copy, test results, and so on. Examples of the data storage 206 can be, but not limited to, a
20 memory, a file server, a data server, the Cloud, and so on. The memory may include one or more computer-readable storage media. The memory may include non-volatile storage elements. Examples of such non-volatile storage elements may include magnetic hard discs, optical discs, floppy discs, flash memories, or forms of electrically programmable memories (EPROM) or electrically erasable
25 and programmable (EEPROM) memories. In addition, the memory may, in some examples, be considered a non-transitory storage medium. The term “non-transitory” may indicate that the storage medium is not embodied in a carrier wave or a propagated signal. However, the term “non-transitory” should not be interpreted to mean that the memory is non-movable. In some examples, the
30 memory can be configured to store larger amounts of information than the

memory. In certain examples, a non-transitory storage medium may store data that can, over time, change (e.g., in Random Access Memory (RAM) or cache).

[0029] FIG. 3 is an example diagram illustrating various modules of the digital controller 204 for creating the digital copy of the battery pack 100 and managing the battery pack 100 when the battery pack is deployed in the at least one field, according to embodiments as disclosed herein.

[0030] The digital controller 204 includes an interface 302, a specification managing module 304, an assembly rules managing module 306, a testing module 308, a digital copy creation module 310, a configuration module 312, a field diagnostic testing module 314 and a performance tracing module 316.

[0031] The interface 302 enables at least one user and/or at least one external application and/or an external entity (the assembly line 202, the data storage 206 and so on) to interface with the digital controller 204. Examples of the interface 302 can be, but not limited to, a display, one or more switches, one or more user interfaces and so on. The interface 302 can comprise of one or more communication interfaces, which enable the digital controller 204 to communicate with the external application, the user device, the external entity and so on.

[0032] The specification managing module 304 can be configured to define the specification/configuration information of the components of the battery pack 100. The specifications can comprise of one or more characteristics of the batteries, such as, but not limited to, electrode materials, energy density, voltage/current, Capacity, Cold cranking amps (CCA), specific power, specific power energy density, C-rates, load, Watts and Volt-amps (VA), State-of-health (SoH), State-of-charge (SoC), State-of-function (SoF), and so on. The specifications can be defined automatically and/or manually.

[0033] The specification managing module 304 also defines thresholds for performing the tests on the components and the battery pack 100. The thresholds can be defined and dynamically varied for different levels/types of the tests based on the specification associated with the components/the battery pack 100. The

specification managing module 304 can communicate the thresholds to the battery pack assembly line 202 through the interface 302 for performing the assembly line tests and the high rate discharge tests.

5 [0034] The assembly rules managing module 306 can be configured to generate the indication for assembling the battery pack 100. The indication includes information about the components that can be used by the battery pack assembly line 202 to assemble the battery pack 100 and the rules for assembling the battery pack 100.

10 [0035] The assembly rules managing module 306 scans/checks the components as the components enter the battery pack assembly line 202 and receives the results of the tests performed on that components from the battery pack assembly line 202. Based on the results of the tests, the assembly rules managing module 306 selects the components for assembling the battery pack 100. Further, the assembly rules managing module 306 receives the specification
15 of the selected components and defines the rules for assembling the battery pack 100 using the selected components. In an embodiment herein, the rules can be derived automatically based on the specification. The rules can comprise a value/values/range of values for one or more of the parameters present in the specification. In an embodiment herein, the rules can be provided manually to the
20 assembly line 202. In an embodiment herein, the rules can be updated dynamically based on the components and the associated specification/configuration information. The assembly rules managing module 306 generates the indication based on the selected components and the rules defined for assembling the battery pack using the selected components. The
25 assembly rules managing module 306 communicates the indication to the assembly line 202 through the interface 302. Thus, the indication provides details to the battery pack assembly line 202 on how and which components to be used for assembling the battery pack 100.

30 [0036] The testing module 308 can be configured to perform the second level of tests on the assembly battery pack 100 and the associated components.

[0037] The testing module 308 performs the insulation tests on the battery pack 100 and the associated components to ensure that there is no leakage current across the components of the battery pack 100. For example, heavy voltage can be applied on the battery pack/the associated components to ensure that there is no leakage current.

[0038] The testing module 308 also performs the telematics/communication tests on the battery pack 100 and the associated components. The communication tests can be at least one of tests to check whether the battery pack 100 is in compliance with network operator' quality and the communication network requirements, Global Positioning System (GPS) tests, General Packet Radio Service (GPRS) tests, cloud test, cellular network compatibility (3G, 4G, 5G and so on) tests, Bluetooth compatibility tests, device durability tests, short range communication tests, wireless communication tests, BMS command set tests, SCU command set tests, CAN communication tests and so on.

[0039] The testing module 308 also performs the current calibration tests on the on the battery pack 100 and the associated components. The testing module 308 also performs the EOL tests on the battery pack 100 and the associated components to determine efficiency of the battery pack 100, efficiency of the components of the battery pack 100 and an overall efficiency of the assembled battery pack 100. The EOL tests can be at least one of charging, discharging and charging tests, capacity tests, temperature tests or the like. The EOL tests can be performed to monitor charging/discharging efficiency of the battery cells, cell voltage deviations, temperature rises and so on.

[0040] The digital copy creation module 310 can be configured to create the digital copy of the battery pack 102. The digital copy creation module 310 can receive the results of the tests from the testing module 308 and checks the results of the tests with the corresponding thresholds (defined by the specification managing unit 304) to validate whether the battery pack 100 and the associated components have passed the tests. If the battery pack 100 and the associated

components have passed the tests successfully, then the digital copy creation module 310 certifies the battery pack 100 to deploy in the at least one field and ensures a completion of manufacturing of the battery pack 100. Thereafter, the digital copy creation module 310 creates the digital copy of the battery pack 100 with respect to each component of the battery pack 100. The digital copy creation module 310 stores the digital copy of the corresponding battery copy 100 in the data storage 206.

[0041] The configuration module 312 can be configured to enable the battery pack 100 to operate in a field mode, so that the battery pack 100 can be connected with the digital controller 204 and can send data/alert conditions to the digital controller 204 using the interface 302. The data can be telemetry data, battery data, battery usage data, or the like.

[0042] The field diagnostic test module 314 can be configured to perform field diagnostic tests on the battery pack(s) 102 connected with the digital controller 204. The field diagnostic tests can be at least one of charging and discharging tests (in the charging stations), tests for measuring changes in vital parameters (capacitance, resistance, voltage and so on) at cell level of the battery pack 100. The field diagnostic test module 314 may perform the field diagnostic tests continuously or on a periodic basis. The field diagnostic test module 314 may also perform the field diagnostic tests on receiving the alert conditions from the battery pack 102. The field diagnostic test module 314 stores results of the field diagnostic tests in the data storage 206.

[0043] The performance tracking module 316 can be configured to monitor, trace and manage the battery pack 100 that is deployed in the field. The performance tracking module 316 receives results of the field diagnostic tests from the diagnostic test module 316 and performs correctional procedures on the battery pack 100. The correctional procedures can include modifying one or more specifications, re-balancing of the battery cells or the like. After performing the correctional procedures, the performance tracking module 316 can update the digital copy by including the performed correctional procedures.

[0044] The performance tracking module 316 can also be configured to monitor performance of the battery pack 100 and the associated components continuously and determine degradation in the performance of the battery pack 100 and the associated components. The performance tracking module 316 can also configured for identifying malfunctioning components within the battery pack 100 on receiving the alert conditions/data from the battery pack 100. The malfunctioning components can be identified using the digital copy and the data/alert conditions received from the battery pack 100. The performance tracking module 316 further checks whether the malfunctioning components are the active components based on the configuration information of that components included in the digital copy. If the malfunctioning components are the active components, then the performance tracking module 316 instructs the configuring module 312 to address the malfunctioning components by performing a malfunction troubleshooting process. The malfunction troubleshooting process includes analyzing original configuration of the malfunctioning components and changing the configurations of the malfunctioning components.

[0045] FIG. 4 is a flow diagram 400 illustrating a method for lifetime management of the at least one battery pack 100, according to embodiments as disclosed herein.

[0046] At step 402, the method includes assembling, by the battery pack assembly line 202, the battery pack 100 using the at least one component. The battery pack assembly line 202 performs the assembly tests and the high rate discharge tests using the threshold defined by the digital controller 204 and sends the results of the corresponding tests to the digital controller 204. In response to the results of the assembly tests, the battery pack assembly line 202 receives the indication from the digital controller 204, which assists the battery pack assembly line 202 to determine how and which components are to be used for assembling the battery pack 100. Based on the indication, the battery pack assembly line 202 assembles the battery pack 100.

[0047] At step 404, the method includes creating, by the digital controller 204, the digital copy of the battery pack 100 by certifying the battery pack 100 to deploy in the field. Once the battery pack is assembled, the digital controller 204 performs the second level of tests such as, but not limited to, the insulation tests, the communication tests, the current calibration tests, the EOL tests or the like on the battery pack and the associated components. If the battery pack and the associated components pass the tests, then the digital controller 204 ensures the completion of creation of the battery pack 100. Further, the digital controller 204 creates the digital copy of the battery pack 100 based on the results of the assembly tests and the second level of tests, the configuration information and unique identifiers of the battery pack 100 and the associated components, the thresholds used for the tests, the rules defined for assembling the battery pack 100 and so on.

[0048] At step 406, the method includes monitoring, tracing and managing, by the digital controller 204, the battery pack 100 using the created digital copy when the battery pack 100 is deployed in the at least one field. The digital controller 204 enables the battery pack 100 to operate in the field mode, so that the digital controller 204 can connect with the digital controller 204. The digital controller 204 further performs the field diagnostic tests/third level of tests on the battery pack 100 and performs the correctional procedures on the battery pack 100 based on the results of the field diagnostic tests. The digital controller 204 further monitors the battery pack 100 and determines the performance degradation and the malfunctioning components in the battery pack 100 using the digital copy and the data/alert conditions received from the battery pack 100. If the malfunctioning components are the active components, then the digital controller 204 can remotely address the malfunctioning components. Further, the digital controller 204 can update the digital copy of the corresponding battery pack after performing the correctional procedures and addressing the malfunctioning components. Thus, creation of the digital copy can be useful to aid in troubleshooting issues and establishing warranty claim on the components of the battery pack 100 in the field.

[0049] The various actions, acts, blocks, steps, or the like in the method and the flow diagram 400 may be performed in the order presented, in a different order or simultaneously. Further, in some embodiments, some of the actions, acts, blocks, steps, or the like may be omitted, added, modified, skipped, or the like
5 without departing from the scope of the invention.

[0050] Embodiments herein provide a smart automation method to create a digital twin/digital copy for each addressable component of a battery pack and the battery pack itself during manufacturing of the battery pack.

[0051] Embodiments herein provide a smart automation method for
10 monitoring ongoing health of the battery pack and improving performance for the battery pack.

[0052] Embodiments herein creates the digital twin by capturing following features:

Quality Snapshot: The quality snapshot of the battery pack can be produced and
15 maintained by testing the components individually during an assembly process. The quality snapshot can further generate tests data at multiple stages of the assembly process.

Configuration management: The configuration management can be useful in understanding which of the components constitute the battery pack, since each
20 component has a unique identifier and some components are active components that can be addressed remotely. For example, the active components can be addressed using software via an interface supporting at least one communication network based on their configuration information.

EOL testing: Once the battery pack is manufactured and certified to be deployed
25 in a field (a vehicle, a charging station, a power supply and so on), the battery pack can be configured to operate in the field mode where the battery pack starts continually transmitting telemetry data to a remote server (a digital controller of a battery pack management system). The remote server can then manage the battery pack efficiently.

Field Diagnostics: Field diagnostic tests and following correctional procedures can be performed on the battery pack that can involve re-balancing of the battery cells in the battery pack. The on-going field diagnostic tests and the correctional procedures can be stored in the digital twin.

5 Traceability: The battery pack performance can be affected by performance of the components. In case of alerts received from the battery pack or degradation in performance or malfunction troubleshooting requires identification of the components. The components can be identified by looking up the configuration information of the digital twin of the affected battery pack.

10 [0053] The embodiments disclosed herein can be implemented through at least one software program running on at least one hardware device and performing network management functions to control the elements. The elements shown in FIGs. 1, 2a, 2b and FIG. 3 can be at least one of a hardware device, or a combination of hardware device and software module.

15 [0054] The embodiments disclosed herein describe methods and systems for lifetime management of battery packs by creating digital copies of the battery packs. Therefore, it is understood that the scope of the protection is extended to such a program and in addition to a computer readable means having a message therein, such computer readable storage means contain program code means for
20 implementation of one or more steps of the method, when the program runs on a server or mobile device or any suitable programmable device. The method is implemented in a preferred embodiment through or together with a software program written in e.g. Very high speed integrated circuit Hardware Description Language (VHDL) another programming language, or implemented by one or
25 more VHDL or several software modules being executed on at least one hardware device. The hardware device can be any kind of portable device that can be programmed. The device may also include means which could be e.g. hardware means like e.g. an ASIC, or a combination of hardware and software means, e.g. an ASIC and an FPGA, or at least one microprocessor and at least one memory
30 with software modules located therein. The method embodiments described herein

could be implemented partly in hardware and partly in software. Alternatively, the invention may be implemented on different hardware devices, e.g. using a plurality of CPUs.

[0055] The foregoing description of the specific embodiments will so fully
5 reveal the general nature of the embodiments herein that others can, by applying
current knowledge, readily modify and/or adapt for various applications such
specific embodiments without departing from the generic concept, and, therefore,
such adaptations and modifications should and are intended to be comprehended
within the meaning and range of equivalents of the disclosed embodiments. It is to
10 be understood that the phraseology or terminology employed herein is for the
purpose of description and not of limitation. Therefore, while the embodiments
herein have been described in terms of embodiments, those skilled in the art will
recognize that the embodiments herein can be practiced with modification within
the spirit and scope of the embodiments as described herein.

CLAIMS

1. A battery pack management system (100) comprising:

a data storage (206),

a battery pack assembly line (202),

and

a digital controller (204),

wherein the digital controller (204) is configured for:

creating at least one digital copy of at least one battery pack (100), wherein the digital copy is stored in the data storage (206); and

monitoring, tracing and managing the at least one battery pack (100) using the created at least one digital copy after deploying the at least one battery pack (100) in at least one field,

wherein the battery pack assembly line (202) is configured for assembling at least one battery pack using at least one component of a plurality of components, which further comprises:

performing a plurality of first level of tests on the plurality of components to be used for assembling the at least one battery pack (100) using at least one threshold defined by the digital controller (204), wherein the plurality of first level of tests include assembly line tests and high rate discharge tests;

receiving at least one indication from the digital controller (204) upon communicating results of the plurality of first level of tests to the digital controller (204), wherein the indication includes information about the at least one component selected by the digital controller (204) for assembling the at least one battery pack (100) and at least one rule for assembling the at least one battery pack (100); and

assembling the at least one battery pack (100) using the at least one selected component based on the at least one indication received from the digital controller (204), wherein the digital controller (204) is further configured for:

configuring the at least one battery pack (100) to operate in an field mode;

performing a plurality of third level of tests on the at least one battery pack (100) based on at least one alert condition received from the at least one battery pack (100), wherein the plurality of third level of tests include field diagnostic tests;

performing at least one correctional procedure on the at least one battery pack (100) based on a result of the plurality of third level of tests; and

updating the at least one digital copy corresponding to the at least one battery pack (100) based on the performed correctional procedure. .

2. The battery pack management system of claim 1, wherein the digital controller (204) selects the at least one component for assembling the at least one battery pack (100) based on the results of the plurality of first level of tests.

3. The battery pack management system of claim 1, wherein the digital controller (204) defines the at least one rule for assembling the at least one battery pack (100) based on configuration information of the at least one selected component.

4. The battery pack management system of claim 1, wherein the digital controller (204) is further configured for:

performing a plurality of second level of tests on at least one of the assembled at least one battery pack (202) and the at least one component of the battery pack (100), wherein the plurality of second level of tests include at least one of insulation tests, communication tests, current calibration tests, End of Line (EOL) tests;

certifying the at least one battery pack (100) if results of the plurality of second level of tests satisfies with at least one threshold; and

creating the at least one digital copy of the at least one battery pack (100) after certifying the at least one battery pack (100).

5. The battery pack management system of claim 4, wherein the digital copy includes the configuration information of the at least one battery pack and the at least one component, the results of the plurality of first level of tests corresponding to the at least one component associated with the at least one battery pack (100), results of the plurality of second level of tests corresponding to the at least one battery pack and the associated at least one component, unique identifiers of the at least one battery pack and the associated at least one component, the at least one threshold used for performing the plurality of first level of tests and the

plurality of second level of tests and the at least one rule defined for assembling the at least one battery pack (100).

6. The battery pack management system of claim 1, wherein the digital controller (204) is further configured for:

monitoring performance of the at least one battery pack (100) and the associated at least one component to determine performance degradation in the at least one battery pack (100) and the associated at least one component;

identifying at least one malfunctioning component within the at least one battery pack (100) on receiving the at least one alert condition from the at least one battery pack (100), wherein the at least one malfunctioning component is identified using the at least one digital copy and data received from the at least one battery pack (100); and

addressing the at least one malfunctioning component within the at least one battery pack (100) if the at least one malfunctioning component is an active component.

7. A method for lifetime management of battery packs, the method comprising:

creating, by a digital controller (204), at least one digital copy of at least one battery pack (100), wherein the digital copy is stored in a data storage (206);

monitoring, tracing and managing, by the digital controller (204), the at least one battery pack (100) using the created at least one digital copy after deploying the at least one battery pack (100) in at least one field;

assembling, by a battery pack assembly line (202), at least one battery pack using at least one component of a plurality of components;

performing, by the battery pack assembly line (202), a plurality of first level of tests on the plurality of components to be used for assembling the at least one battery pack (100) using at least one threshold defined by the digital controller (204), wherein the plurality of first level of tests include assembly line tests and high rate discharge tests;

receiving, by the battery pack assembly line (202), at least one indication from the digital controller (204) upon communicating results of the plurality of first level of tests to the digital controller (204), wherein the indication includes information about the at least one component selected by the digital controller (204) for assembling the at least one battery pack (100) and at least one rule for assembling the at least one battery pack (100); and

assembling, by the battery pack assembly line (202), the at least one battery pack (100) using the at least one selected component based on the at least one indication received from the digital controller (204),

wherein monitoring, tracing and managing, by the digital controller (204), the at least one battery pack (100) comprises:

configuring the at least one battery pack (100) to operate in an field mode;

performing a plurality of third level of tests on the at least one battery pack (100) based on at least one alert condition received from the at least one battery pack (100), wherein the plurality of third level of tests include field diagnostic tests;

performing at least one correctional procedure on the at least one battery pack (100) based on a result of the plurality of third level of tests; and

updating the at least one digital copy corresponding to the at least one battery pack (100) based on the performed correctional procedure.

8. The method of claim 7, further comprises: selecting, by the digital controller (204), the at least one component for assembling the at least one battery pack (100) based on the results of the plurality of first level of tests.

9. The method of claim 7, further comprises: defining, by the digital controller (204) the at least one rule for assembling the at least one battery pack (100) based on configuration information of the at least one selected component.

10. The method of claim 7, wherein creating, by the digital controller (204), the at least one digital copy includes:

performing a plurality of second level of tests on at least one of the assembled at least one battery pack (202) and the at least one component of the battery pack (100), wherein the plurality of second level of tests include at least one of insulation tests, communication tests, current calibration tests, End of Line (EOL) tests;

certifying the at least one battery pack (100) if results of the plurality of second level of tests satisfies with at least one threshold; and

creating the at least one digital copy of the at least one battery pack (100) after certifying the at least one battery pack (100).

11. The method of claim 10, wherein the digital copy includes the configuration information of the at least one battery pack and the at least one component, the results of the plurality of first level of tests corresponding to the at least one component associated with the at least one battery pack (100), results of the plurality of second level of tests corresponding to the at least one battery pack and the associated at least one component, unique identifiers of the at least one battery pack and the associated at least one component, the at least one threshold used for performing the plurality of first level of tests and the plurality of second level of tests and the at least one rule defined for assembling the at least one battery pack (100).

12. The method of claim 7, further comprises:

monitoring performance of the at least one battery pack (100) and the associated at least one component to determine performance degradation in the at least one battery pack (100) and the associated at least one component;

identifying at least one malfunctioning component within the at least one battery pack (100) on receiving the at least one alert condition from the at least one battery pack (100), wherein the at least one malfunctioning component is identified using the at least one digital copy and data received from the at least one battery pack (100); and

addressing the at least one malfunctioning component within the at least one battery pack (100) if the at least one malfunctioning component is an active component.