

SYSTEM FOR BALANCING PLURALITY OF CELLS WITHIN BATTERY
PACK AND METHOD THEREOF

FIELD OF THE INVENTION

[0001] The present invention relates to a battery pack, and more particularly relates to a system and method for balancing a plurality of cells within the battery pack.

BACKGROUND OF THE INVENTION

[0002] Electric energy stored in devices such as batteries are, of late, being used as energy sources in applications such as transportation, telecom, and the like. These batteries include multiple cells connected to one other in one of series, parallel, and a combination thereof and placed within a battery pack. The number of cells and capacity of the cells depend on the application the battery pack is used for.

[0003] During manufacturing of cells and assembling of the cells within the battery pack, each of the cells are graded based on one of, but not limited to, voltage and capacity. Therefore, voltage rating of each of the cells arranged within the battery pack are the same. However, during the course of operation of the battery pack, State of Charge (SOC) of each cell within the battery pack may vary. This phenomenon of variation in voltage of the cells is known as cell unbalancing. Constructional arrangement of the cells owing to which the cells at the different locations within the battery pack are exposed to different levels of heat, electro chemical reactions within the cells and so on are causes responsible for the cells to be unbalanced.

[0004] Imbalanced cells within the battery pack cause the battery pack to operate at a reduced capacity that what the battery pack was designed for, thereby leading to inefficient operation of the battery pack and reduced life of the battery pack. In order to achieve maximum efficiency of the battery pack it is necessary that the SOC and voltage levels of each of the multiple cells are maintained at an equal level.

[0005] Balancing of the cells are achieved by one of active balancing, passive balancing, and a combination thereof. Active balancing is a balancing technique

that redistributes electric energy from each of the multiple cells during charge and discharge cycles of the same. More specifically, in active balancing, the battery pack is provided with components, such as, but not limited to, an inductor, a capacitor, and a combination thereof electrically coupled to the multiple cells. The components aid in transferring energy from overcharged cells to undercharged cells, and thereby maintaining the SOC and the voltage level of each of the multiple cells at an equal level. In addition, active balancing technique makes use of bi-directional fly back convertors, DC/DC convertors, or buck-boost convertors for each cell to one of transfer power and receive power, as per the SOC and voltage level of each of the multiple cells.

[0006] However, usage of additional components reduces the compactness of the battery pack, and further increases the cost of the battery pack. Further, as each of the multiple cells make use of the fly back convertors, the battery pack is susceptible to Electromagnetic Interference (EMI), additional hardware components are required to ensure the robustness of the battery pack.

[0007] In order to balance each of the multiple cells of the battery pack via passive balancing, the battery pack is provided with components, such as resistors. Accordingly, the excess energy from the overcharged cells are dissipated in the form of heat. As the excess energy is dissipated in the form of heat and not used in an efficient manner, the battery pack is considered to be inefficient. Further, due to the heat dissipated within the battery pack, the battery pack is designed such that the battery pack is capable of handling the excess heat. Further, additional components, such as sensors, needs to be provided within the battery pack to continuously monitor the battery pack and alert a user in case of emergency. In addition, the time taken to balance the multiple cells via the passive balancing is greater in comparison to time taken for balancing each of the multiple cells via active balancing.

[0008] In view of the above, an alternative system is required to balance multiple cells of the battery pack and ensure efficient operation of the battery pack.

SUMMARY OF THE INVENTION

[0009] One or more embodiments of the present invention provide a system and method for balancing a plurality of cells within a battery pack.

[0010] In one aspect of the invention, a system for balancing a plurality of cells arranged within a battery pack is disclosed. The system includes a plurality of sensors electrically coupled to the plurality of cells. The plurality of sensors is configured to measure multiple operational parameters of each of the plurality of cells. The system further includes a switching unit electrically coupled to each of the plurality of cells and a controlling unit communicably coupled to each of the plurality of sensors and the switching unit. The controlling unit is configured to determine an energy value for each of the plurality of cells based on data pertaining to the multiple operational parameters of each of the plurality of cells. Based on the energy value, the controlling unit determines an energy delta for each of the plurality of cells. The controlling unit is further configured to selectively operate the switching unit for a time period. The time period is determined based on the energy delta for each of the plurality of cells to allow transfer of energy from at least one of the plurality of cells to a storage unit. Subsequent to transfer of energy, each of the plurality of cells is at an ideal operating state, and the plurality of cells are balanced.

[0011] In another aspect of the invention, a method of balancing a plurality of cells arranged within a battery pack is disclosed. The method includes determining an energy value for each of the plurality of cells. The energy value is determined based on data pertaining to multiple operational parameters of each of the plurality of cells. The method further includes determining an energy delta for each of the plurality of cells, based on the energy value. Based on the energy delta, the controlling unit determines a time period for selectively operating a switching unit. Accordingly, the switching unit allows transfer of energy from at least one of the plurality of cells to the storage unit. Subsequent to transfer of energy, each of the plurality of cells is at an ideal operating state, and the plurality of cells are balanced.

[0012] In yet another aspect of the invention, a battery pack is disclosed. The battery pack includes a plurality of cells arranged within the battery pack. The

battery pack further includes a plurality of sensors electrically coupled to the plurality of cells to measure multiple operational parameters of each of the plurality of cells and a switching unit electrically coupled to each of the plurality of cells. The battery pack further includes a controlling unit communicably coupled to each of the plurality of sensors and the switching unit. The controlling unit is configured to receive data from the plurality of sensors pertaining to the operational parameters of each of the plurality of cells. The controlling unit further determines a plurality of energy values based on the data pertaining to the multiple operational parameters of each of the plurality of cells. Subsequent to determining the energy values, the controlling unit selects a minimal energy value from the plurality of determined energy values. The controlling unit, thereafter, determines an energy delta for each of the plurality of cells. The energy delta is a difference between the energy value of each cell and the minimal energy value. Based on the energy delta, the controlling unit determines a time period for selectively operating a switching unit. Accordingly, the switching unit allows transfer of energy from at least one of the plurality of cells to the storage unit. Subsequent to transfer of energy, each of the plurality of cells is at an ideal operating state, and the plurality of cells are balanced.

[0013] Other features and aspects of this invention will be apparent from the following description and the accompanying drawings. The features and advantages described in this summary and in the following detailed description are not all-inclusive, and particularly, many additional features and advantages will be apparent to one of ordinary skill in the relevant art, in view of the drawings, specification, and claims hereof. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter, resort to the claims being necessary to determine such inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Reference will be made to embodiments of the invention, examples of which may be illustrated in the accompanying figures. These figures are intended to be illustrative, not limiting. The accompanying figures, which are incorporated

in and constitute a part of the specification, are illustrative of one or more embodiments of the disclosed subject matter and together with the description explain various embodiments of the disclosed subject matter and are intended to be illustrative. Further, the accompanying figures have not necessarily been drawn to scale, and any values or dimensions in the accompanying figures are for illustration purposes only and may or may not represent actual or preferred values or dimensions. Although the invention is generally described in the context of these embodiments, it should be understood that it is not intended to limit the scope of the invention to these particular embodiments.

[0015] **FIG. 1** is a block diagram of an environment to which a system for balancing a plurality of cells arranged within a battery pack is implemented, according to one or more embodiments of the present invention;

[0016] **FIG. 2** is a schematic representation of the system of the **FIG. 1** for balancing at least one of the plurality of cells, according to one or more embodiments of the present invention;

[0017] **FIG. 3** is a block diagram of the battery pack of the **FIG. 1** including the system to balance the plurality of cells of **FIG. 1**, in accordance with one or more embodiments of the present invention;

[0018] **FIG. 4** is a bloc diagram of the battery pack of the **FIG. 1** having a controlling unit located at a location remotely accessible by the user, in accordance with one or more embodiments of the present invention;

[0019] **FIG. 4A** is a graphical representation of energy value ($E_{(\text{cell}-n)}$) in each cells of the battery pack of the **FIG. 1**, in accordance with one or more embodiments of the present invention;

[0020] **FIG. 4B** is a graphical representation of energy delta (D_n) of each cells of the battery pack of the **FIG. 1**, in accordance with one or more embodiments of the present invention;

[0021] **FIG. 4C** is a graphical representation of voltage of each cells of the battery pack of the **FIG. 1** prior to balancing of each of the cells, in accordance with one or more embodiments of the present invention;

[0022] **FIG. 4D** is a graphical representation of voltage set point ($VS_{(cap-n)}$) of each storage unit of the battery pack of the **FIG. 1**, in accordance with one or more embodiments of the present invention;

[0023] **FIG. 4E** is a graphical representation of a time period determined for balancing each cells of the battery pack of the **FIG. 1**, in accordance with one or more embodiments of the present invention;

[0024] **FIG. 4F** is a graphical representation of voltage of each cells of the battery pack, of the **FIG. 1**, at an ideal operating state, in accordance with one or more embodiments of the present invention; and

[0025] **FIG. 5** is a flow chart of a method of balancing the plurality of cells arranged within a battery pack of the **FIG.1**, according to one or more embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0026] Reference will now be made in detail to specific embodiments or features, examples of which are illustrated in the accompanying drawings. Wherever possible, corresponding or similar reference numbers will be used throughout the drawings to refer to the same or corresponding parts. References to various elements described herein, are made collectively or individually when there may be more than one element of the same type. However, such references are merely exemplary in nature. It may be noted that any reference to elements in the singular may also be construed to relate to the plural and vice-versa without limiting the scope of the invention to the exact number or type of such elements unless set forth explicitly in the appended claims. Moreover, relational terms such as first and second, and the like, may be used to distinguish one entity from the other, without necessarily implying any actual relationship or between such entities.

[0027] **FIG. 1** illustrates a block diagram of an environment **100** to which a system **115** for balancing a plurality of cells **110** arranged within a battery pack **105** is implemented, according to one or more embodiments of the present invention. In the illustrated embodiment, the battery pack **105** is employed as an energy source in applications such as transportation, telecom, household

appliances, and the like. Although the illustrated embodiment depicts a single battery pack **105**, it is to be understood that multiple battery packs may be used as per the requirement, without depicting from the scope of the present disclosure.

[0028] The battery pack **105** includes a plurality of cells **110** arranged therein. Each of the plurality of cells **110** is electrically coupled to the each other in one of a series connection, a parallel connection and a combination thereof. The battery pack **105** further includes multiple arrays (not shown) electrically coupled to each other. Each of the multiple arrays include the plurality of cells **110** electrically coupled to each other. Capacity of each of the plurality of cells **110** is dependent on one of user requirements, the application the battery pack **105** is used for, and a combination thereof.

[0029] In one embodiment, each of the plurality of cells **110** is one of, but not limited to, a Lithium ion (Li-ion), a Lead acid gel, and Nickel metal hydride. In an alternate embodiment, composition of each of the plurality of cells **110** is lithium or lithium polymer cells (referred to as “lithium”) combined with a nickel hydrate battery cells. In alternate embodiments, any suitable battery cell composition may be used, including, but not necessarily limited to, lithium ion, zinc air, zinc oxide, super charged zinc oxide, and fuel cells.

[0030] Each of the plurality of cells **110** is further electrically coupled to the system **115**. In the illustrated and preferred embodiment, the system **115** is positioned within the battery pack **105**. In alternate embodiments, the system **115** is located at a location remotely accessible to a user. The system **115** receives data pertaining to multiple operational parameters of each of the plurality of cells **110**. The multiple operational parameters are one of, but not limited to, current, voltage, and temperature of each of the plurality of cells. In one embodiment, the battery pack **105** includes a battery telematics unit **405** (as shown in **FIG. 4**) receiving and temporarily storing the data pertaining to multiple operational parameters of each of the plurality of cells **110**.

[0031] Based on the multiple operational parameters, the system **115** allows transfer of energy from at least one of the plurality of cells **110** to a storage unit **120**. The storage unit **120** is electrically coupled to each of the plurality of cells **110** and is also communicably coupled to the system **115**. In one embodiment, if

the plurality of cells **110** are connected to each other in series connection, then number of storage units **120** is equivalent to the number of cells connected in series in the battery pack **110**. In another embodiment, if the plurality of cells **110** are connected in parallel connection, then a single storage unit **120** is sufficient. The storage unit **120** is one of, but not limited to, a ultracapacitor, a pseudo capacitor, a supercapacitor, a Double Layer Capacitor (DLC), and a battery pack.

[0032] Subsequent to the transfer of energy, each of the plurality of cells **110** are at an ideal operating state and balancing of the plurality of cells **110** is achieved. The ideal operating state of each of the plurality of cells **110** is achieved when a voltage delta of each of the plurality of cells **110** is below a threshold value. Constructional and operational features of the system **115**, and a method of balancing the plurality of cells **110** will be explained in detail with respect to the following figures.

[0033] The battery pack **105** is further electrically coupled to a load **125**. As mentioned above, the battery pack **105** is used as the energy source in applications such as, but not limited to, transportation and telecom. Accordingly, if the battery pack **105** is employed in the transportation sector, the load **125** is multiple components of an electric vehicle. Similarly, if the battery pack is employed in the telecom sector, the load **125** is one of, but not limited to, a telecom tower. In addition, the battery pack **105** is configured to be removably coupled to a charging unit **130** for charging each of the plurality of cells **110** arranged within the battery pack **105**.

[0034] The system **115** further transmits the data pertaining to the multiple operational parameters of the battery pack **105** to a server **135** via a network **140**. In one embodiment, subsequent to transmission of the data related to the multiple parameters from the system **115** to the server **135**, copy of the relevant data is automatically from the system **115**. By doing so, ensures that the system **115** is not accumulated with previously stored data which is already transmitted to the server **135**. Advantageously, the system **115** is not burdened with large volume of data beyond the capacity of the system **115**, thereby ensuring that effective monitoring service is provided and improving the operational efficiency of the system **115**. It may be understood that the server **135** may be implemented in a

variety of computing systems, such as a mainframe computer, a network server, cloud, and the like.

[0035] The server **135** is in communication with the battery pack **105** via the network **140**. In one embodiment, a Secure Hardware Extension (SHE) unit is embedded within the battery pack **105**. The SHE unit ensures that a secure communication of data takes place between the system **115** and the server **135**, thereby preventing third party access to data. In an embodiment, the network **140** can include wired and/or wireless connections such as, but not limited to, local area network (LAN), Bluetooth, Near Field Communication (NFC), infrared, WIFI, GPRS, LTE, Edge and the like.

[0036] In addition, the system **115** is in communication with a user device **145** via the network **140**. As such, the user device **145** receives notifications pertaining to the multiple operational parameters of the battery pack **105** and the plurality of cells **110**. In certain embodiments, the user device **145** enables the user to manually switch off the battery pack **105** from a remote location in case of an emergency. In addition, the user device **145** is communicably coupled to the server **135**. Further, one of the server **135** and the system **115** is configured to provide the user with periodic reports regarding health of the battery pack **105**. The user device **145** is one of, but not limited to, a mobile phone, a portable computer, a personal digital assistant, a handheld device, a laptop computer, and a display unit in the electric vehicle.

[0037] Referring to **FIG. 2**, **FIG. 2** illustrates a schematic representation of the system **115** for balancing at least one of the plurality of cells **110**, according to one or more embodiments of the present invention. The system **115** is coupled to each of the plurality of cells **110** arranged within the battery pack **105**. The system **115** aids in transferring energy from at least one of the plurality of cells **110** to at least one of the storage unit **120**.

[0038] As mentioned earlier, the battery pack **105** includes the plurality of cells **110**. However, for the purpose of description, the system **115** is here forth explained with respect to “a single cell **110**” for the embodiment as illustrated in the **FIG. 2**, and should nowhere be construed as limiting the scope of the present

disclosure. Accordingly, the plurality of cells **110** is hereinafter referred to as “the cell **110**”.

[0039] The system **115** includes a plurality of sensors **210**, hereinafter referred to as “the sensors **210**”. The sensors **210** are electrically coupled to the cell **110** to measure the multiple operational parameters of the cell **110**. The sensors **210** are coupled one of wirelessly and by means of wire to the cell **110**, depending on application of the sensor **210**. The sensors **210** include, but is not limited to, a current sensor, a voltage sensor, an impedance sensor, and a temperature sensor. The multiple operational parameters correspond to, but is not limited to, current, voltage, temperature and State of Charge (SOC) of the cell **110**.

[0040] The system **115** further includes a switching unit **215** electrically coupled to the cell **110**. More specifically, an anode of the cell **110** is electrically coupled to a component **220** of the switching unit **215**. The component **220** aids in maintaining one of a unidirectional and a controlled bi-directional flow of energy from the anode of the cell **110** to the component **220**, and restricts flow in opposite direction. In one embodiment, the component **220** is a diode. In an alternate embodiment, the component **220** is a Metal Oxide Semiconductor Field Effect Transistor (MOSFET).

[0041] In the illustrated embodiment, the switching unit **215** includes a current control component **225** coupled to the component **220**. The current control component **225** aids in providing protection to the system **115** from current surges. During transfer of energy from the cell **110** to the storage unit **120** a potential difference arises. In certain cases, the storage unit **120** may be subjected to damages such as short circuit and the like. In such cases the current control component **220**, advantageously, protects the cell **110** and in turn the battery pack **105** from damages. In one embodiment, the current control component **225** is one of, but not limited to, a Field Effect Transistor (FET). In another embodiment, the system **115** is provided independent of the current control component **225**.

[0042] The switching unit **215** further includes a switch **230**. The switch **230** is configured to one of allow and prevent transfer of energy from the cell **110** to the storage unit **120**. The switch **230** is one of, but not limited to, a electromechanical switch, a manual switch, a toggle switch, a Metal Oxide Semiconductor Field

Effect Transistor (MOSFET), an Insulated Gate Bipolar Transistor (IGBT), and a Junction Field Effect Transistor (JFET).

[0043] The switching unit **215**, including the component **220**, the current control component **225**, and the switch **230**, is thereafter coupled to the storage unit **120**. Thus, the cell **110** is electrically coupled to the at least one storage unit **120** via the switching unit **215**. The storage unit **120** is one of, but not limited to, a ultracapacitor, a pseudo capacitor, a supercapacitor, a Double Layer Capacitor (DLC), and a battery pack.

[0044] The system **115** further includes a controlling unit **235**. The controlling unit **235** may include at least one processor **240**, an input/output (I/O) interface unit **245**, and a memory **250**. The at least one processor **240** may be implemented as one or more microprocessors, microcomputers, microcontrollers, digital signal processors, central processing units, state machines, logic circuitries, and/or any devices that manipulate signals based on operational instructions. Among other capabilities, the at least one processor **240** is configured to fetch and execute computer-readable instructions stored in the memory **250**.

[0045] The I/O interface unit **245** may include a variety of software and hardware interfaces, for example, a web interface, a graphical user interface, Light Emitting Diode (LED) and the like. The I/O interface unit **245** may allow the user to interact with the controlling unit **235** directly or through the user device **145**. Further, the I/O interface unit **245** may enable the controlling unit **235** to communicate with other computing devices, such as the server **135** and external data servers (not shown). The I/O interface **245** may facilitate multiple communications within a wide variety of networks and protocol types, including wired networks, for example, LAN, cable, etc., and wireless networks, such as WLAN, cellular, or satellite. In one embodiment, The I/O interface unit **245** may include one or more ports for connecting a number of devices to one another or to another server.

[0046] The memory **250** may include any computer-readable medium known in the art including, for example, volatile memory, such as static random access memory (SRAM) and dynamic random access memory (DRAM), and/or non-

volatile memory, such as read only memory (ROM), erasable programmable ROM, flash memories, hard disks, optical disks, and magnetic tapes.

[0047] The controlling unit **235** is communicably coupled to the sensors **210** to receive data pertaining to the multiple operational parameters of the cell **110**. The controlling unit **235** is further communicably coupled to the switching unit **215**. More specifically, the controlling unit **235** is one of electrically and communicably coupled to the switch **230** of the switching unit **215**. The controlling unit **235** is configured to selectively operate the switch **230** to allow the transfer of energy from the cell **110** to the storage unit **120**. Working and operation of the controlling unit **235** to balance the cell **110** will be explained in more detail with respect to **FIG. 3**.

[0048] Referring to **FIG. 3**, **FIG. 3** illustrates a block diagram **300** of the battery pack **105** including the system **115** to balance the plurality of cells **110**, in accordance with one or more embodiments of the present invention. As mentioned earlier, the battery pack **105** includes the plurality of cells **110**. Each of the plurality of cells **110** are electrically coupled to each other in one of the series connection, the parallel connection and combination thereof.

[0049] For the purpose of description and explanation, the plurality of cells **110** are here forth explained with respect to a first cell **110a**, a second cell **110b**, a third cell **110c**, and a fourth cell **110d**. It is however to be understood that the plurality of cells **110** may include additional number of cells than the first cell **110a**, the second cell **110b**, the third cell **110c**, and the fourth cell **110d** as per requirement of the application, and should nowhere be construed as limiting the scope of the present disclosure.

[0050] As per the illustrated embodiment, each of the first, the second, the third, and the fourth cell **110a-d** are coupled to each other in series connection. In alternate embodiments, each of the first, the second, the third, and the fourth cell **110a-d** may be coupled to each other in one of parallel connection and combination of series connection and parallel connection.

[0051] As each of the first, the second, the third, and the fourth cell **110a-d** is connected to each other in series connection, the battery pack **105** includes a first storage unit **120a**, a second storage unit **120b**, a third storage unit **120c**, and a

fourth storage unit **120d** also connected to each other in series. In the illustrated embodiment, each of the first, the second, the third, the fourth storage unit **120a-d** is a supercapacitor. In alternative embodiments, each of the first, the second, the third, the fourth storage unit **120a-d** is the ultracapacitor, the pseudo capacitor, the Double Layer Capacitor (DLC), and the battery pack.

[0052] Further, the cell **110** is electrically coupled to the at least one storage unit **120** via the switching unit **215**, as mentioned earlier in **FIG. 2**. Accordingly, the battery pack **105** includes a first switching unit **215a**, a second switching unit **215b**, a third switching unit **215c**, and a fourth switching unit **215d**.

[0053] With reference to the illustrated embodiment in **FIG. 3**, the first cell **110a** is electrically coupled to the first storage unit **120a** via the first switching unit **215a**, the second cell **110b** is electrically coupled to the second storage unit **120b** via the second switching unit **215b**, the third cell **110c** is electrically coupled to the third storage unit **120c** via the third switching unit **215c**, and the fourth cell **110d** is electrically coupled to the fourth storage unit **120d** via the fourth switching unit **215d**.

[0054] The battery pack **105** further includes the plurality of sensors **210** (as shown in **FIG. 2**) communicably coupled to each of the first cell **110a**, the second cell **110b**, the third cell **110c**, and the fourth cell **110d** via a first communication line **320a**, a second communication line **320b**, a third communication line **320c**, and a fourth communication line **320d**. The plurality of sensors **210** are configured to measure the multiple operational parameters of each of the first, the second, the third, and the fourth cell **110a-d**. The measured multiple operational parameters are thereafter transmitted to the controlling unit **235** of the battery pack **105** via the first, the second, the third, and the fourth communication line **320a-d**. In the illustrated embodiment, the controlling unit **235** is located within the battery pack **105**. In alternative embodiments, the controlling unit **235** may be located at a location remotely accessible by the user.

[0055] On receiving the multiple operational parameters, the controlling unit **235** determines an energy value ($E_{(\text{cell-n})}$) of each of the first, the second, the third, and the fourth cell **110a-d**. The energy value ($E_{(\text{cell-n})}$) of each of the first, the second, the third, and the fourth cell **110a-d** is defined as energy stored therein

with respect to a capacity of each of the first, the second, the third, and the fourth cell **110a-d** at a given point of time.

[0056] The energy value ($E_{(cell-n)}$) of each of the first, the second, the third, and the fourth cell **110a-d** is equivalent to a ratio of a product of a nominal voltage, SOC and the capacity of each of the first, the second, the third, and the fourth cell **110a-d** to hundred.

$$\text{Energy value } (E_{(cell-n)}) = \{(\text{Nominal Voltage}_{(cell-n)}) * (\text{SOC}_{(cell-n)}) * (\text{Capacity}_{(cell-n)})\} / 100 \dots\dots\dots (Eq. 1)$$

[0057] In one embodiment, the controlling unit **235** determines the energy value ($E_{(cell-n)}$) at pre-set intervals, as defined by the user. In an alternative embodiment, the controlling unit **235** determines the energy value ($E_{(cell-n)}$) is continuously determining and monitoring the energy value ($E_{(cell-n)}$) of each of the first, the second, the third, and the fourth cell **110a-d**. In one embodiment, the controlling unit **235** determines the voltage and current of each of the first, the second, the third, and the fourth cell **110a-d** based on the measured operational parameters. Thereafter, the controlling unit **235** determines the energy value ($E_{(cell-n)}$) of each of the first, the second, the third, and the fourth cell **110a-d** by mapping the determined voltage value with a respective energy value as per an energy look up table, as provided for the battery pack **105**. In an alternative embodiment, the controlling unit **235** determines the energy value ($E_{(cell-n)}$) of each of the first, the second, the third, and the fourth cell **110a-d** based on a coulomb count of each of the energy value ($E_{(cell-n)}$) of each of the first, the second, the third, and the fourth cell **110a-d**.

[0058] Subsequently, the controlling unit **235** compares the determined energy value ($E_{(cell-n)}$) of each of the first, the second, the third, and the fourth cell **110a-d** with each other to select a minimal energy value ($E_{(cell-min)}$). The minimal energy value ($E_{(cell-min)}$) is the least energy value of at least one of the first, the second, the third, and the fourth cell **110a-d**.

[0059] The controlling unit **235**, further, determines an energy delta (D_n) for each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**. The energy delta of each of the first, the second, the third, and the fourth cell **110a-d** is a difference between the energy value ($E_{(cell-n)}$) of each of the first,

the second, the third, and the fourth cell **110a-d** and the minimal energy value ($E_{(\text{cell-min})}$) of at least one of the first, the second, the third, and the fourth cell **110a-d**.

$$\text{Energy Delta}(D_n) = E_{(\text{cell-n})} - E_{(\text{cell-min})} \dots\dots\dots (Eq. 2)$$

[0060] On calculation of the energy delta (D_n) of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**, the controlling unit **235** determines excess energy available in at least one of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**. The excess energy in the at least one of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** is to be transferred to one of the first, the second, the third, and the fourth storage unit **120a-d** to balance the cells. Thereby, advantageously, reducing wastage of energy in form of heat.

[0061] Subsequently, the controlling unit **235** determines a voltage set point ($VS_{(\text{cap-n})}$) for each of the first, the second, the third, and the fourth storage unit **120a-d** on the basis of the energy to be transferred from at least one of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** to the first, the second, the third, and the fourth storage unit **120a-d**, respectively. The voltage set point ($VS_{(\text{cap-n})}$) is the projected voltage level of each of the first, the second, the third, and the fourth storage unit **120a-d** subsequent to receiving the energy from at least one of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**, respectively. The voltage set point ($VS_{(\text{cap-n})}$) for each of the first, the second, the third, and the fourth storage unit **120a-d** is a square root of a ratio of two times the energy value ($E_{(\text{cell-n})}$) of each of the first, the second, the third, and the fourth cell **110a-d** to a capacitance of each of the first, the second, the third, and the fourth storage unit **120a-d**.

$$\text{Voltage Set Point } (VS_{(\text{cap-n})}) = \text{Sqrt}\{(2 * \text{Energy value } (E_{(\text{cell-n})}) / \text{Capacitance } (C_{(\text{cap-n})})\} \dots\dots\dots (Eq. 3)$$

[0062] The controlling unit **235** further determines a time period (t_n) for operating the switching unit **215**. More specifically, the controlling unit **235** determines the time period (t_n) for operating a first, a second, a third, and a fourth switch **230a-d** provided in each of the first, the second, the third and the fourth switching unit **215a-d**, respectively. The controlling unit **235** determines the time

period (t_n) for operating each of the first, the second, the third, and the fourth switch **230a-d** based on the energy delta (D_n) of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**, respectively. More specifically, the controlling unit **235** determines the time period (t_n) by determining time required to charge at least one of the first, the second, the third, and the fourth storage unit **120a-d**. Accordingly, the time period (t_n) is defined as a ratio of a product of the capacitance and voltage set point ($VS^{(cap-n)}$) for each of the first, the second, the third, and the fourth storage unit **120a-d**, respectively to the charging current.

$$\text{Time period } (t_n) = \{ \text{Capacitance } (C_{(cap-n)}) * \text{Voltage Set Point } (VS_{(cap-n)}) \} / \text{Charging Current} \dots\dots\dots (Eq. 4)$$

[0063] The charging current is a predefined value based on, but not limited to, the capacitance of the battery pack **105**, PCB thickness, ratings of the switching unit **215**.

[0064] In one embodiment, the controlling unit **235** further, determines one of an equivalent resistance and an ON-state resistance of each of the first, the second, the third, and the fourth switch **230a-d** based on the energy delta (D_n) of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**, respectively

[0065] The controlling unit **235** communicates with each of the first, the second, the third, and the fourth switch **230a-d** via a first communication line **325a**, a second communication line **325b**, a third communication line **325c**, and a fourth communication line **325d**. Accordingly, the controlling unit **235** selectively operates each of the first, the second, the third, and the fourth switch **230a-d** for the determined time period (t_n). In one embodiment, the controlling unit **235** selectively operates each of the first, the second, the third, and the fourth switch **230a-d** for the determined time period (t_n) based on one of, but not limited to, the equivalent resistance and the ON-state resistance of each of the first, the second, the third, and the fourth switch **230a-d**, the voltage set point ($VS_{(cap-n)}$) of each of the first, the second, the third, and the fourth storage unit **120a-d**, and a combination thereof.

[0066] Accordingly, the excess energy from at least one of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** is transferred to the first, the second, the third, the fourth storage unit **120a, 120b, 120c, and 120d**, respectively. The energy transferred from at least one of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** is based on the energy delta of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**.

[0067] Subsequent to transfer of the energy, state of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** is at the ideal operating state, and each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** is considered to be balanced.

[0068] In another embodiment, the controlling unit **235** selectively operates each of the each of the first, the second, the third, and the fourth switch **230a-d** based on the voltage delta of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**.

[0069] Accordingly, the ideal operating state of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** is achieved when a voltage delta (VD_n) of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** is lesser than a threshold value. The voltage delta (VD_n) is defined as a difference between a voltage value (V_(cell-n)) of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** and a minimal voltage value (V_(cell-min)) of at least one of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**.

$$\text{Voltage Delta(VD}_n\text{)} = V(\text{cell-n}) - V(\text{cell-min}) \dots\dots\dots (\text{Eq.2})$$

[0070] The threshold value pertains to a voltage range determined based on the type and composition of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**.

[0071] Further, the excess energy transferred from at least one of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** to the first, the second, the third, the fourth storage unit **120a, 120b, 120c, and 120d**, respectively is advantageously utilized to one of recharge the at least one of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**,

provide energy to the load **125** and a combination thereof. In addition, the excess energy available in at least one of the first, the second, the third, and the fourth cell **110a**, **110b**, **110c**, and **110d** is reutilized and not wasted in the form of heat and the like. As such, the system **115** ensures optimum utilization of the energy available in the battery pack **105** and further ensures efficient utilization of the battery pack **105**.

[0072] In this regard, the battery pack **105** includes a cell-load switch **305**, a DC connection switch **310**, and a storage unit switch **315**. Each of the cell-load switch **305**, the DC connection switch **310**, and the storage unit switch **315** are communicably coupled to the controlling unit **235**. On actuation of the cell-load switch **305** and the storage unit switch **315**, at least one of the first, the second, the third, and the fourth cell **110a**, **110b**, **110c**, and **110d** is charged via the first, the second, the third, the fourth storage unit **120a**, **120b**, **120c**, and **120d**. Further, on actuation of the cell-load switch **305** and the DC connection switch **310**, each of the first, the second, the third, and the fourth cell **110a-d** one of discharges to provide energy to the load **125** and is charged by the charging unit **130**. Furthermore, on actuation of the DC connection switch **310** and the storage unit switch **315**, the energy stored in each of the first, the second, the third, the fourth storage unit **120a**, **120b**, **120c**, and **120d** is used to provide energy to the load **125**.

[0073] FIG. 4 illustrates an exemplary embodiment in which a controlling unit **410** of the system **405** of the battery pack **105** is located at the location remotely accessible by the user, according to one or more embodiments of the present invention. As mentioned earlier, the battery pack **105** includes the plurality of cells **110**, the switching unit **215** coupled to the plurality of cells **110**, the storage unit **120**, and the plurality of sensors **210** coupled to the plurality of cells **110** and the storage unit **120**. The operation and arrangement of the battery pack **105** with respect to the plurality of cells **110**, the switching unit **215**, the storage unit **120**, and the plurality of sensors **210** is similar to as illustrated and described with in respect to FIG. 2 and FIG. 3. Therefore, for the sake of brevity the same will not be described again in the description for FIG. 4.

[0074] The battery pack **105** further communicates with the controlling unit **410** located at the remote location via the network **140**. The plurality of sensors **210** transfers the data pertaining to the multiple operational parameters of the plurality of cells **110** via the network **140**. Based on the multiple operational parameters, the controlling unit **410** determines the energy value ($E_{(\text{cell-n})}$) of each of the plurality of cells **110**, the energy delta (D_n), the voltage set point ($VS_{(\text{cap-n})}$) of each of the at least one storage unit **120**, the time period (t_n), and the voltage value ($V_{(\text{cell-n})}$) of each of the plurality of cells **110** based on the respective equations as provided. Thereafter, the controlling unit **410** allows transfer of energy from at least one of the plurality of cells **110** to the at least one storage unit **120**.

[0075] The controlling unit **410**, of the illustrated embodiment, is further configured to provide real time information with respect to the energy value ($E_{(\text{cell-n})}$) of each of the plurality of cells **110**, the energy delta (D_n), the voltage set point ($VS_{(\text{cap-n})}$) of each of the at least one storage unit **120**, the time period (t_n) for balancing, and the voltage value ($V_{(\text{cell-n})}$) to the user. Accordingly, the controlling unit **410** communicates with the user device **145** of the user via the server **135**. In one embodiment, the controlling unit **410** provides the user with the real time information in the form of illustrative graphs as shown in **FIGS. 4A-F**. In another embodiment, the controlling unit **410** notifies the user on the user device **145** by pop up messages and the like, and thereby alert the user of imbalanced cells. In yet another embodiment, the user is enabled to manually trigger the balancing of the at least one plurality of cells **110** via the controlling unit **410**. As such, the battery pack **105** is continuously monitored by the user.

[0076] Various embodiments disclosed herein are to be taken in the illustrative and explanatory sense and should in no way be construed as limiting of the present disclosure.

Industrial Applicability

[0077] The present disclosure provides the system **115** for balancing the plurality of cells **110** arranged within the battery pack **105**. The system **115** enables balancing of the plurality of cells **110** during one of charging the battery pack **105** and in real time during operation of the battery pack **105**. The battery

pack **105** includes the plurality of cells **110** and at least one storage unit **120** disposed therein. The battery pack **105** further includes the system **115** for balancing the plurality of cells **110**. The system **115** includes the controlling unit **235** to efficiently control the switching unit **215** to aid in transfer of excess energy from the plurality of cells **110** to the storage unit **120**.

[0078] The controlling unit **235** in communication with the switching unit **215** aids in transfer of excess energy in real time, and as such ensures continuous operation of the battery pack **105**. The energy thus transferred is utilized to one of recharge the at least one of the plurality of cells **110**, provide energy to the load **125**, and combination thereof. As such, the system **115** advantageously ensures minimum wastage of the excess energy as heat, and ensures efficient operation of the battery pack **105**. As the excess energy is reutilized by the battery pack without dissipation of excess heat, the battery pack **100** does not require any additional components to compensate for excess heat. Further, as the system **115** does not utilize hardware components, such as fly back convertors, susceptible to Electro Magnetic Interference (EMI) and Electro Magnetic Compatibility (EMC), the system **100** need not include additional hardware to ensure robustness of the battery pack **105**, and thereby ensuring compactness of the battery pack **100**.

[0079] **FIG. 5** is a flow chart of a method **500** of balancing the plurality of cells **110** arranged within a battery pack **105**, according to one or more embodiments of the present invention. For the purpose of description and explanation, the method **500** is described with respect to the embodiment as illustrated in **FIG. 3**.

[0080] At step **502**, the controlling unit **235** of the system **115** determines the energy value ($E_{(cell-n)}$) for each of the plurality of cells **110**.

[0081] With reference to the embodiment illustrated in **FIG. 3**, the battery pack **105** includes the plurality of sensors **210** to measure the multiple operational parameters of each of the first, the second, the third, and the fourth cell **110a-d**. The plurality of sensors **210** further transmits the data pertaining to the multiple operational parameters to the controlling unit **235** via the first communication line **320a**, the second communication line **320b**, the third communication line **320c**, and the fourth communication line **320d**. The controlling unit **235** determines the energy value of each of the first, the second, the third, and the

fourth cell **110a, 110b, 110c, and 110d** with respect to the capacity of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** at the given point of time.

[0082] The energy value ($E_{(cell-n)}$) of each of the first, the second, the third, and the fourth cell **110a-d** is equivalent to a ratio of a product of a nominal voltage, SOC and the capacity of each of the first, the second, the third, and the fourth cell **110a-d** to hundred. Accordingly, as per **Eq. 1**, the controlling unit **235** determines the energy value ($E_{(cell-n)}$) of each of the first, the second, the third, and the fourth cell **110a-d**. Thus, the energy value ($E_{(cell-1)}$) of the first cell **110a** is 2448J, the energy value ($E_{(cell-2)}$) of the second cell **110b** is 2880J, the energy value ($E_{(cell-3)}$) of the third cell **110c** is 2592J, and the energy value ($E_{(cell-4)}$) of the fourth cell **110d** is 2749J.

[0083] With reference to the graphical illustration as illustrated in **FIG. 4A**, the energy value ($E_{(cell-n)}$) is depicted along the Y-axis and each of the first, the second, the third, and the fourth cell **110a-d** is depicted along the X-axis. It is evident from the graphical representation of **FIG. 4A** that the energy values ($E_{(cell-n)}$) of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** are different, and hence the controlling unit **235** determines that the battery pack **105** is imbalanced. On determination of the energy value ($E_{(cell-n)}$), the controlling unit **235** stores the same in the memory **250** of the controlling unit **235**. In one embodiment, the controlling unit **235** further transfers the energy value ($E_{(cell-n)}$) of each of the first, the second, the third, and the fourth cell **110a-d** to the server **135**, and thereby improves the computational efficiency of the controlling unit **235**.

[0084] Further, the controlling unit **235** compares the energy value ($E_{(cell-1-4)}$) of each of the first, the second, the third, and the fourth cell **110a-d** with each other to determine the minimal energy value ($E_{(cell-min)}$) to select the minimal energy value. The controlling unit **235** compares the energy value of the first cell **110a** ($E_{(cell-1)}$), the energy value of the second cell **110b** ($E_{(cell-2)}$), the energy value of the third cell **110c** ($E_{(cell-3)}$), and the energy value of the fourth cell **110d** ($E_{(cell-4)}$) with each other. It is evident from the graphical representation shown in **FIG. 4A**, the energy value of the first cell **110a**, ($E_{(cell-1)}$), is the least in comparison to

the energy value of the second cell **110b** ($E_{(\text{cell-2})}$), the energy value of the third cell **110c** ($E_{(\text{cell-3})}$), and the energy value of the fourth cell **110d** ($E_{(\text{cell-4})}$). Hence, the controlling unit **235** selects the energy value of the first cell **110a** ($E_{(\text{cell-1})}$) as the minimal energy value ($E_{(\text{cell-min})}$).

[0085] At step **504**, based on the determined energy value the method **500** determines the energy delta (D_n) for each of the plurality of cells **110**. The energy delta (D_n) of each of the plurality of cells **110** is a difference between the energy value ($E_{(\text{cell-n})}$) of each of the plurality of cells **110** and the minimal energy value ($E_{(\text{cell-min})}$) of at least one of the plurality of cells **110**. **FIG. 4B** illustrates a graphical representation depicting energy delta (D_n) along the Y-axis and each of the first, the second, the third, and the fourth cell **110a-d** along the X-axis.

[0086] As mentioned earlier, the energy value for the first cell **110a** ($E_{(\text{cell-1})}$) is 2448J, and the minimal energy value ($E_{(\text{cell-min})}$) is also 2448J. Accordingly, as per the **Eq. 2**, the energy delta for the first cell **110a**, $D_1 = 0\text{J}$, as shown in **FIG. 4B**.

[0087] Further, the energy value for the second cell **110b** ($E_{(\text{cell-2})}$) is 2880J and the minimal energy value ($E_{(\text{cell-min})}$) is 2448J. Accordingly, as per the **Eq. 2**, the energy delta for the second cell **110b**, $D_2 = 432\text{J}$, as shown in **FIG. 4B**.

[0088] Further, the energy value for the third cell **110c** ($E_{(\text{cell-3})}$) is 2592J and the minimal energy value ($E_{(\text{cell-min})}$) is 2448J. Accordingly, as per the **Eq. 2**, the energy delta for the third cell **110c**, $D_3 = 144\text{J}$, as shown in **FIG. 4B**.

[0089] Furthermore, the energy value for the fourth cell **110d** ($E_{(\text{cell-4})}$) is 2749J and the minimal energy value ($E_{(\text{cell-min})}$) is 2448J. Accordingly, as per the **Eq. 2**, the energy delta for the fourth cell **110d**, $D_4 = 301\text{J}$.

[0090] Simply said, the first cell **110a** has the minimal available energy and hence no excess energy is to be transferred to the first storage unit **120a**. The second cell **110b** has 432J of excess energy required to be transferred to the second storage unit **120b**. Likewise, the third cell **110c** has 144J of excess energy required to be transferred to the third storage unit **120c**, and the fourth cell **110d** has 301J of excess energy to be transferred to the fourth storage unit **120d**.

[0091] Based on the multiple operational parameters, the controlling unit **235** further determines voltage (V_n) of each of the first, the second, the third, and the fourth cell **110a-d**, as illustrated in the **FIG. 4C**. The **FIG. 4C** depicts voltage

along the y-axis and each of the first, the second, the third, and the fourth cell **110a-d** along the x-axis. As per the graph, the voltage of the first cell **110a**, V_1 is equivalent to 4000V, the voltage of the second cell **110b**, V_2 is equivalent to 4150V, the voltage of the third cell **110c**, V_3 is equivalent to 4070V, and the voltage of the fourth cell **110d**, V_4 is equivalent to 4100V.

[0092] Thereafter, the controlling unit **235** determines the voltage set point ($VS_{(cap-n)}$) for each of the first, the second, the third, and the fourth storage unit **120a-d** on the basis of the energy to be transferred. The voltage set point ($VS_{(cap-n)}$) for each of the first, the second, the third, and the fourth storage unit **120a-d** is a square root of a ratio of the energy value ($E_{(cell-n)}$) of each of the first, the second, the third, and the fourth cell **110a-d** to a capacitance of each of the first, the second, the third, and the fourth storage unit **120a-d**. Further, as per **FIG. 4D**, the voltage set point ($VS_{(cap-n)}$) is depicted along the Y-axis and each of the first, the second, the third, and the fourth storage unit **120a-d** along the X-axis.

[0093] As per the **Eq. 3**, the voltage set point for the first storage unit **120a**, $VS_{(cap-1)} = 0V$, as shown in **FIG. 4D**. Likewise, as per the **Eq. 3**, the voltage set point for the second storage unit **120b**, $VS_{(cap-2)} = 4.16V$, the voltage set point for the third storage unit **120c**, $VS_{(cap-3)} = 2.40V$, and the voltage set point for the fourth storage unit **120d**, $VS_{(cap-4)} = 3.47V$, as shown in **FIG. 4D**.

[0094] At step **506**, the method **500** includes the step of determining the time period to operate the switching unit **215** based on the energy delta (D_n) of each of the plurality of cells **110**. Referring to **FIG. 3**, the controlling unit **235** determines the time period (t) for operating each of the first, the second, the third, and the fourth switch **230a-d** based on the energy delta (D_n) of each of the first, the second, the third, and the fourth cell **110a**, **110b**, **110c**, and **110d**, respectively. More specifically, the controlling unit **235** determines the time period (t_n) by determining time required to charge at least one of the first, the second, the third, and the fourth storage unit **120a-d**. The time period (t_n) is defined as the ratio of the product of the capacitance and voltage set point ($VS_{(cap-n)}$) for each of the first, the second, the third, and the fourth storage unit **120a-d**, respectively to the charging current. Further, as per **FIG. 4E**, the time period (t_n) is depicted along

the Y-axis and each of the first, the second, the third, and the fourth switch **230a-d** along the X-axis.

[0095] The controlling unit **235** determines the time period (t_2) for operating the second switch **230b** to transfer 432J of energy from the second cell **110b** to the second storage unit **120b**. As per **Eq. 4**, time period (t_2) = 51.96 seconds, as shown in **FIG. 4E**.

[0096] Likewise, the controlling unit **235** determines the time period (t_3) and the time period (t_4) to transfer 144J and 301J of energy from each of the third cell **110c** and the fourth cell **110d** to the third and the fourth storage unit **120c**, **120d**, respectively. As per **Eq. 4**, time period (t_3) = 30 seconds and time period (t_4) = 43.37 seconds, as shown in **FIG. 4E**. As the energy delta for the first cell **110a**, $D_1 = 0J$, the controlling unit **235** need not operate the first switch **230a**, and as such need not calculated time period (t_1).

[0097] In one embodiment, the controlling unit **235** further, determines one of an equivalent resistance and an ON-state resistance of each of the first, the second, the third, and the fourth switch **230a-d** based on the energy delta (D_n) of each of the first, the second, the third, and the fourth cell **110a**, **110b**, **110c**, and **110d**, respectively.

[0098] At step **508**, the method **500** includes the step of selectively operating the switching unit **215** for the time period (t) to allow transfer of the energy from at least one of the plurality of cells **110** to a storage unit **120**. On transfer of the energy, each of the plurality of cells **110** is at the ideal operating state and the plurality of cells **110** are balanced.

[0099] Referring to the **FIG. 3**, the controlling unit **235** communicates with each of the first, the second, the third, and the fourth switch **230a-d** via the first communication line **325a**, the second communication line **325b**, the third communication line **325c**, and the fourth communication line **325d**. Accordingly, the controlling unit **235** selectively operates each of the second, the third, and the fourth switch **230a-d** for the respective time periods. In one embodiment, the controlling unit **235** selectively operates each of the first, the second, the third, and the fourth switch **230a-d** for the respective time periods based on one of, but not limited to, the equivalent resistance and the ON-state resistance of each of the

first, the second, the third, and the fourth switch **230a-d**, the voltage set point of each of the first, the second, the third, and the fourth storage unit **120a-d**, and a combination thereof.

[00100] Accordingly, 432J of energy from the second cell **110b** is transferred to the second storage unit **120b**, 144J of energy from the third cell **110c** is transferred to third storage unit **120c**, and 301J of energy from the fourth cell **110d** is transferred to fourth storage unit **120d** via the first, the second, the third, and the fourth switch **230a-d**, respectively. More specifically, the controlling unit **235** operates the second switch **230b** for time period $(t_2) = 36.74$ to allow transfer of 432J of energy from the second cell **110b** to the second storage unit **120b**. Likewise, the controlling unit **235** operates the third switch **230c** and the fourth switch **230d** for time period $(t_3) = 21.21$ seconds and time period $(t_4) = 30.67$ seconds, respectively, to allow transfer of 144J of energy from the third cell **110c** to the third storage unit **120c** and 301J of energy from the fourth cell **110d** to the fourth storage unit **120d**, respectively.

[00101] Subsequent to transfer of the energy, state of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** is at the ideal operating state, and each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** is considered to be balanced.

[00102] After balancing of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**, the controlling unit **235** determines voltage V_n of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d**, as shown in **FIG. 4F**. It is evident from the graphs illustrated in **FIG. 4F** and **FIG. 4C**, voltage (V_{1-4}) of each of the first, the second, the third, and the fourth cell **110a, 110b, 110c, and 110d** is below the threshold value and is operating at an ideal operating state.

[00103] While aspects of the present invention have been particularly shown and described with reference to the embodiments above, it will be understood by those skilled in the art that various additional embodiments may be contemplated by the modification of the disclosed machines, systems and methods without departing from the scope of what is disclosed. Such embodiments should be

understood to fall within the scope of the present invention as determined based upon the claims and any equivalents thereof.

CLAIMS

1. A system (115) for balancing a plurality of cells (110) arranged within a battery pack (105), the system (115) comprising:
 - a plurality of sensors (210) electrically coupled to the plurality of cells (110) to measure multiple operational parameters of each of the plurality of cells (110);
 - a switching unit (215) electrically coupled to each of the plurality of cells (110); and
 - a controlling unit (235) communicably coupled to each of the plurality of sensors (210) and the switching unit (215), the controlling unit (235) configured to:
 - determine an energy value ($E_{(cell-n)}$) for each of the plurality of cells (110) based on data pertaining to the multiple operational parameters of each of the plurality of cells (110);
 - determine, based on the energy value ($E_{(cell-n)}$), an energy delta (D_n) for each of the plurality of cells (110); and
 - selectively operate the switching unit (215) for a time period (t_n), the time period (t_n) determined based on the energy delta (D_n) for each of the plurality of cells (110) to allow transfer of energy from at least one of the plurality of cells (110) to a storage unit (120), wherein subsequent to transfer of energy, each of the plurality of cells (110) is at an ideal operating state and the plurality of cells (110) are balanced.
2. The system (115) as claimed in claim 1, wherein the energy delta (D_n) is a difference between the energy value ($E_{(cell-n)}$) of each of the plurality of cells (110) and a minimal energy value ($E_{(cell-min)}$) of at least one of the plurality of cells (110).
3. The system (115) as claimed in claim 1, wherein the ideal operating state is achieved when a voltage delta (VD_n) of each of the plurality of cells (110) is lesser than a threshold value, the voltage delta (VD_n) is a difference between a voltage value ($V_{(cell-n)}$) of each of the plurality of

- cells (110) and a minimal voltage value ($V_{(\text{cell-min})}$) of at least one of the plurality of cells (110).
4. The system (115) as claimed in claim 3, wherein the threshold value pertains to a voltage range determined based on a type of the plurality of cells (110).
 5. The system (115) as claimed in claim 1, wherein each of the plurality of cells (110) is electrically coupled to each other in one of a series connection, a parallel connection, and a combination thereof.
 6. The system (115) as claimed in claim 1, wherein the multiple operational parameters correspond to, but not limited to, current, voltage, and temperature of each of the plurality of cells (110).
 7. The system (115) as claimed in claim 1, wherein the storage unit (120) is one of, but not limited to, a battery pack, and a capacitor.
 8. The system (115) as claimed in claim 1, wherein the switching unit (215) is one of, but not limited to, a switch, a transistor, and a MOSFET.
 9. The system (115) as claimed in claim 1, wherein the controlling unit (235) selectively operates the switching unit (215) for the determined time period (t_n) based on one of, but not limited to, a voltage set point ($V_{S(\text{cap-n})}$) of the storage unit (120), an equivalent resistance/ON-state resistance of the switching unit (215), and a combination thereof.
 10. The system (115) as claimed in claim 1, wherein energy transferred from at least one of the plurality of cells (110) to the storage unit (120) is utilized to one of recharge at least one of the plurality of cells (110), provide energy to a load (125), and a combination thereof.
 11. A method (500) of balancing a plurality of cells (110) arranged within a battery pack (105), the method (500) comprising:
 - determining an energy value ($E_{(\text{cell-n})}$) for each of the plurality of cells (110) based on data pertaining to multiple operational parameters of each of the plurality of cells (110);
 - determining, based on the energy value ($E_{(\text{cell-n})}$), an energy delta (D_n) for each of the plurality of cells (110);

determining, based on the energy delta (D_n), a time period (t_n) to operate a switching unit (215); and

selectively operating the switching unit (215) for the time period (t_n) to allow transfer of energy from at least one of the plurality of cells (110) to a storage unit (120), wherein subsequent to transfer of energy, each of the plurality of cells (110) is at an ideal operating state and the plurality of cells (110) are balanced.

12. The method (500) as claimed in claim 11, wherein the energy delta (D_n) is a difference between the energy value ($E_{(\text{cell-n})}$) of each of the plurality of cells (110) and a minimal energy value ($E_{(\text{cell-min})}$) of at least one of the plurality of cells (110).
13. The method (500) as claimed in claim 11, wherein the ideal operating state is achieved when a voltage delta (VD_n) of each of the plurality of cells (110) is lesser than a threshold value, the voltage delta (VD_n) is a difference between a voltage value ($V_{(\text{cell-n})}$) of each of the plurality of cells (110) and a minimal voltage value ($V_{(\text{cell-min})}$) of at least one of the plurality of cells (110).
14. The method (500) as claimed in claim 11, wherein selectively operating the switching unit (215) for the determined time period (t_n) is based on one of, but not limited to, a voltage set point ($VS_{(\text{cap-n})}$) of the storage unit (120), an equivalent resistance/ON-state resistance of the switching unit (215), and a combination thereof.
15. The method (500) as claimed in claim 11, wherein energy transferred from the plurality of cells (110) to the storage unit (120) is utilized to one of recharge at least one of the plurality of cells (110), provide energy to the load (125), and a combination thereof.
16. A battery pack (105) comprising:
 - a plurality of cells (110) arranged within the battery pack (105);
 - a plurality of sensors (210) electrically coupled to the plurality of cells (110) to measure multiple operational parameters of each of the plurality of cells (110);

a switching unit (215) electrically coupled to each of the plurality of cells (110); and

a controlling unit (235) communicably coupled to each of the plurality of sensors (210) and the switching unit (215), the controlling unit (235) configured to:

receive data, from the plurality of sensors (210) pertaining to the operational parameters of each of the plurality of cells (110);

determine a plurality of energy values ($E_{(\text{cell-n})}$) based on data pertaining to the multiple operational parameters of each of the plurality of cells (110), wherein each of the plurality of energy values ($E_{(\text{cell-n})}$) corresponds to one of the plurality of cells (110);

select, a minimal energy value ($E_{(\text{cell-min})}$) from the plurality of determined energy values;

determine, based on the minimal energy value ($E_{(\text{cell-min})}$), an energy delta (D_n) for each of the plurality of cells (110), the energy delta (D_n) is a difference between the energy value ($E_{(\text{cell-n})}$) of each cell and the minimal energy value ($E_{(\text{cell-min})}$);

determine, based on the energy delta (D_n), a time period (t_n) for operating the switching unit (215); and

selectively operate the switching unit (215) for the determined time period (t_n) to allow transfer of energy from each of the plurality of cells (110) to a storage unit (120), wherein subsequent to transfer of energy, each of the plurality of cells (110) is at an ideal operating state and the plurality of cells (110) are balanced, wherein the ideal operating state is achieved when a voltage delta (VD_n) of each of the plurality of cells (110) is lesser than a threshold value.