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Use of heating elements as a diagnostic and optimal setting tool for multiple output dynamically adjustable capacity system

Abstract

A Multiple Output Dynamically Adjustable Capacity (MODACS) and a method of operation of the MODACS. The MODACS includes a cell, a load in thermal communication with the cell, and a processor. A voltage is applied to a load to generate heat at a cell of the MODACS, wherein the heat affects a temperature of the cell. The processor measures a parameter of the cell in response to the heat and controls an operation of the MODACS based on the parameter of the cell.

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Background/Summary

INTRODUCTION

(1) The subject disclosure relates to operation of Multiple Output Dynamically Adjustable Capacity System (MODACS) in a vehicle and, in particular, to a system and method for diagnosing a health of the MODACS using a controlled heating.

(2) A MODACS is a power unit for a plurality of electrical units of a vehicle. The MODACS includes a plurality of energy storage strings that can be configured as needed to meet the changing power demands of the vehicle as required by the plurality of electrical units. Over time, a health of an energy string deteriorates. When this occurs, it can be useful to change an operating set point of the string to be able to meet power demands of the electrical units. Additionally, the operating temperature of the string can have an effect on the efficiency of the string. Accordingly, it is desirable to provide a system and method for diagnosing the state of health of an energy storage string based on a heating signal to thereby establish an operating set point for the energy storage based on the diagnosis.

SUMMARY

(3) In one exemplary embodiment, a method of operating a Multiple Output Dynamically Adjustable Capacity System (MODACS) is disclosed. A voltage is applied to a load to generate heat at a cell of the MODACS, wherein the heat affects a temperature of the cell. A parameter of the cell is measured in response to the heat. An operation of the MODACS is controlled based on the parameter of the cell.

(4) In addition to one or more of the features described herein, the load is at least one of an isolated programmable load, a field effect transistor (FET) internal to the MODACS, a FET powered by the cell, and a FET isolated from the cell. The isolated programmable load is a FET and the voltage is a pulsed voltage pattern applied at a gate of the FET. Applying the voltage to the load generates a current through the cell. The method further includes generating the heat at the by at least one of convection via applying the voltage at the load and conduction via passing the current through the cell. The method further includes measuring the parameter of an equivalent circuit model of the

cell. The method further includes comparing the parameter of the equivalent circuit model to the parameter of an ideal model of the cell to perform at least one of determining a state of health of the MODACS and determining a set point for operating the MODACS based on the state of health. The equivalent circuit model includes an RC pair and the parameter is one of a decay rate of the RC pair and a voltage across the RC pair. Controlling the operation of the MODACS further includes performing at least one of maintaining the temperature of the cell within a desired temperature range, draining the cell, and operating the MODACS at a determined SOC set point for the cell. The method further includes taking the cell offline and applying the voltage to the load when the cell is offline.

(5) In another exemplary embodiment, a Multiple Output Dynamically Adjustable Capacity System (MODACS) is disclosed. The MODACS includes a cell, a load in thermal communication with the cell, and a processor. The processor is configured to apply a voltage to the load to generate heat at the cell, wherein the heat affects a temperature of the cell, measure a parameter of the cell in response to the heat, and control an operation of the MODACS based on the parameter of the cell.

(6) In addition to one or more of the features described herein, the load is at least one of an isolated programmable load, a field effect transistor (FET) internal to the MODACS, a FET powered by the cell, and a FET isolated from the cell. The isolated programmable load is a FET and the voltage is a pulsed voltage pattern applied at a gate of the FET. Applying the voltage to the load generates a current through the cell. The heat is generated at the cell by at least one of convection via applying the voltage at the load and conduction via passing the current through the cell. The processor is further configured to measure the parameter of an equivalent circuit model of the cell. The processor is further configured to compare the parameter of the equivalent circuit model to the parameter of an ideal model of the cell to perform at least one of determining a state of health of the MODACS and determining a set point for operating the MODACS based on the state of health. The equivalent circuit model includes an RC pair and the parameter is one of a decay rate of the RC pair and a voltage across the RC pair. The processor is further configured to control the operation of the MODACS to perform at least one of maintaining the temperature of the cell within a desired temperature range, draining the cell, and operating the MODACS at a determined SOC set point for the cell. The processor is further configured to take the cell offline and apply the voltage to the load when the cell is offline.

(7) The above features and advantages, and other features and advantages of the disclosure are readily apparent from the following detailed description when taken in connection with the accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Other features, advantages and details appear, by way of example only, in the following detailed description, the detailed description referring to the drawings in which:

(2) FIG. **1** shows an embodiment of a motor vehicle, which includes a vehicle body;

(3) FIG. **2** is a functional block diagram of an example battery system of the vehicle;

(4) FIGS. **3**A-**3**B are schematic diagrams including an example battery system including the battery;

(5) FIG. **4** is a functional block diagram of an example implementation of one of the battery modules;

(6) FIG. **5** shows a schematic diagram for a diagnostic circuit for a cell of the battery, in an illustrative embodiment;

(7) FIG. **6** shows a flowchart of a method for diagnosing a cell of the battery, in an illustrative embodiment; and

(8) FIG. **7** shows a schematic diagram illustrating a power system for generating heat at a cell of the battery.

DETAILED DESCRIPTION

(9) The following description is merely exemplary in nature and is not intended to limit the present disclosure, its application or uses. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features. As used herein, the term module refers to processing circuitry that may include an application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that executes one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality.

(10) FIG. **1** shows an embodiment of a motor vehicle **10**, which includes a vehicle body **12** defining, at least in part, an occupant compartment **14**. The vehicle body **12** also supports various vehicle subsystems including a propulsion system **16**, and other subsystems to support functions of the propulsion system **16** and other vehicle components, such as a braking subsystem, a suspension system, a steering subsystem, and others.

(11) The vehicle **10** may be an electrically powered vehicle (EV), a hybrid vehicle or any other vehicle. In an embodiment, the vehicle **10** is an electric vehicle that includes multiple motors and/or drive systems. Any number of drive units may be included, such as one or more drive units for applying torque to front wheels (not shown) and/or to rear wheels (not shown). The drive units are controllable to operate the vehicle **10** in various operating modes, such as a normal mode, a high-performance mode (in which additional torque is applied), all-wheel drive (“AWD”), front-wheel drive (“FWD”), rear-wheel drive (“RWD”) and others.

(12) For example, the propulsion system **16** is a multi-drive system that includes a front drive unit **20** for driving front wheels, and rear drive units for driving rear wheels. The front drive unit **20** includes a front electric motor **22** and a front inverter **24** (e.g., front power inverter module or FPIM), as well as other components such as a cooling system. A left rear drive unit **30**L includes an electric motor **32**L and an inverter **34**L. A right rear drive unit **30**R includes an electric motor **32**R and an inverter **34**R. The inverters **24**, **34**L and **34**R (e.g., power inverter units or PIMs) each convert DC power from a high voltage (HV) battery system **40** to poly-phase (e.g., two-phase, three-phase, six-phase, etc.) alternating current (AC) power to drive the motors **22** and **32**L and **32**R.

(13) As shown in FIG. **1**, the drive systems feature separate electric motors. However, embodiments are not so limited. For example, instead of separate motors, multiple drives can be provided by a single machine that has multiple sets of windings that are physically independent.

(14) As also shown in FIG. **1**, the drive systems are configured such that the front electric motor **22** drives front wheels (not shown) and the rear electric motors **32**L and **32**R drive rear wheels (not shown). However, embodiments are not so limited, as there may be any number of drive systems and/or motors at various locations (e.g., a motor driving each wheel, twin motors per axle, etc.). In addition, embodiments are not limited to a dual drive system, as embodiments can be used with a vehicle having any number of motors and/or power inverters.

(15) In the propulsion system **16**, the drive units **20**, **30**L and **30**R are electrically connected to the battery system **40**. The battery system **40** may also be electrically connected to other electrical components (also referred to as “electrical loads”), such as vehicle electronics (e.g., via an auxiliary power module or APM **42**), heaters, cooling systems and others. The battery system **40** may be configured as a rechargeable energy storage system (RESS).

(16) In an embodiment, the battery system **40** includes a plurality of separate battery assemblies, in which each battery assembly can be independently charged and can be used to independently supply power to a drive system or systems. For example, the battery system **40** includes a first battery assembly such as a first battery pack **44** connected to the inverter **24**, and a second battery pack **46**. The battery pack **44** includes a plurality of battery modules **48**, and the battery pack **46**

includes a plurality of battery modules **50**. Each module **48**, **50** includes a number of individual cells (not shown). In various embodiments, one or more of the battery packs can include a MODACS (Multiple Output Dynamically Adjustable Capacity) battery, as described herein with respect to FIGS. **2-4**.

(17) Each of the front electric motor **22** and the rear motors **32**L and **32**R is a three-phase motor having three phase motor windings. However, embodiments described herein are not so limited. For example, the motors may be any poly-phase machines supplied by poly-phase inverters, and the drive units can be realized using a single machine having independent sets of windings.

(18) The battery system **40** and/or the propulsion system **16** includes a switching system having various switching devices for controlling operation of the battery packs **44** and **46**, and selectively connecting the battery packs **44** and **46** to the drive units **20**, **30**L and **30**R. The switching devices may also be operated to selectively connect the battery pack **44** and the battery pack **46** to a charging system. The charging system can be used to charge the battery pack **44** and the battery pack **46**, and/or to supply power from the battery pack **44** and/or the battery pack **46** to charge another energy storage system (e.g., vehicle-to-vehicle (V2V) and/or vehicle-to-everything (V2X) charging). The charging system includes one or more charging modules. For example, a first onboard charging module (OBCM) **52** is electrically connected to a charge port **54** for charging to and from an AC system or device, such as a utility AC power supply. A second OBCM **53** may be included for DC charging (e.g., DC fast charging or DCFC).

(19) In an embodiment, the switching system includes a first switching device **60** that selectively connects to the battery pack **44** to the inverters **24**, **34**L and **34**R, and a second switching device **62** that selectively connects the battery pack **46** to the inverters **24**, **34**L and **34**R. The switching system also includes a third switching device **64** (also referred to as a "battery switching device") for selectively connecting the battery pack **44** to the battery pack **46** in series.

(20) Any of various controllers can be used to control functions of the battery system **40**, the switching system and the drive units. A controller includes any suitable processing device or unit, and may use an existing controller such as a drive system controller, an RESS controller, and/or controllers in the drive system. For example, a controller **65** may be included for controlling switching and drive control operations as discussed herein.

(21) The vehicle **10** also includes a computer system **55** that includes one or more processing devices **56** and a user interface **58**. The computer system **55** may communicate with the charging system controller, for example, to provide commands thereto in response to a user input. The various processing devices, modules and units may communicate with one another via a communication device or system, such as a controller area network (CAN) or transmission control protocol (TCP) bus.

(22) As illustrated herein, the vehicle **10** is an electric vehicle. In an alternative embodiment, the vehicle **10** can be an internal combustion engine vehicle, a hybrid vehicle, etc.

(23) FIG. **2** is a functional block diagram of an example battery system of the vehicle. The battery **208** has at least two (positive) output terminals and a negative terminal to provide at least two direct current (DC) operating voltages. For example only, the battery **208** may have a first positive (e.g., 48 Volt (V) nominal) terminal **210**, a negative terminal **212**, and a second positive (e.g., 12 V nominal) terminal **214**. While the example of the battery **208** having a 48 V nominal operating voltage and a 12 V nominal operating voltage is provided, the battery **208** may have one or more other operating voltages (as well as a plurality of 12V and/or 48V terminals).

(24) The battery **208** includes a plurality of battery modules, such as a first battery module **224-1**, . . . , and an N-th battery module **224-**N ("battery modules **224**"), where N is an integer greater than or equal to 2. In various implementations, N may be equal to 2, 3, 4, 5, 6, 8, 10, 12, or another suitable number.

(25) As discussed further below with respect to FIG. **4**, each of the battery modules **224** includes multiple battery strings. Each battery string may be individually replaceable. The ability to

individually replace the battery strings may enable the battery **208** to include a shorter warranty period and have a lower warranty experience. The battery strings are also individually isolatable, for example, in the event of a fault in a battery string. In various implementations, the battery **208** may have the form factor of a standard automotive grade 12 V battery.
(26) The battery **208** includes a plurality of switches, such as first switches **232-1**, . . . , N-th switches **232-**N (collectively "switches **232**"). The switches **232** enable the battery strings of the battery modules **224** to be connected in series, parallel, or combinations of series and parallel to provide target output voltages and capacities at the output terminals.
(27) A switch control module **240** controls the switches **232** to provide desired output voltages and capacities at the output terminals.
(28) FIGS. **3**A and **3**B are schematic diagrams including an example battery system including the battery **208**. Sets of the battery strings are connectable in series (via ones of the switches **232**) to the first positive terminal **210** and the negative terminal **212** to provide a first nominal output voltage (e.g., 48 V) via the first positive terminal **210**. Individual ones of the battery strings can be connected (via ones of the switches **232**) to the second positive terminal **214** and the negative terminal **212** to provide a second nominal output voltage (e.g., 12 V) via the second positive terminal **214**. How many of the battery strings are connected to the first positive terminal **210** and the second positive terminal **214** dictates the portions of the overall capacity of the battery **208** available at each of the positive terminals.
(29) As shown in FIG. **3**B, a first set of vehicle electrical components operates using one of the two or more operating voltages of the battery **208**. For example, the first set of vehicle electrical components may be connected to the second positive terminal **214**. The first set of vehicle electrical components may include, for example but not limited to, an electronic control module **114** and other control modules of the vehicle, a starter motor **202**, and/or other electrical loads, such as first 12 V loads **304**, second 12 V loads **308**, other control modules **312**, third 12 V loads **316**, and fourth 12 V loads **320**. In various implementations, a switching device **324** may be implemented.
(30) As shown in FIG. **3**A, a second set of vehicle electrical components operates using another one of the two or more operating voltages of the battery **208**. For example, the second set of vehicle electrical components may be connected to the first positive terminal **210**. The second set of vehicle electrical components may include, for example but not limited to, the generator **206** and various electrical loads, such as 48 V loads **328**. The generator **206** may be controlled to charge the battery **208**.
(31) Each of the switches **232** may be an insulated gate bipolar transistor (IGBT), a field effect transistor (FET), such as a metal oxide semiconductor FET (MOSFET), or another suitable type of switch.
(32) FIG. **4** is a functional block diagram of an example implementation of one of the battery modules **224**, numbered battery module **404**, and one set of the switches **232**. Each of the battery modules **224** may be identical to **404**, and each set of the switches **232** may be connected identically to that of **404**.
(33) The battery module **404** includes three battery strings, **408**, **412**, and **416**. The battery strings **408-416** are identical and each include four battery cells **420**, **424**, **428**, and **432**. The battery cells **420-432** are connected in series to provide the second operating voltage (e.g., 12 V). Each of the battery cells **420-432** may be, for example, a 3 V battery cell or have another suitable voltage to provide the second operating voltage when the battery cells **420-432** are connected in series. The battery cells **420-432** may be, for example lithium ferrophosphate (LFP) battery cells or NMC (nickel-manganese-cobalt) battery cells or have another suitable chemistry. In various embodiments, the battery cells **420-432** can include cathodes that are made of materials such as LFP and NMC and anodes made of graphite, silicon-based materials or Lithium-Titanate (LTO).
(34) Negative terminals of the battery strings **408-416** are connected to the negative terminal **212**.

The negative terminals of the battery strings **408** and **412** are connected to the negative terminal **212** via switches **436** and **440**, respectively, when the switches **436** and **440** are closed. The switches **436** and **440** can open to disconnect the negative terminals of the battery strings **408** and **412** from the negative terminal **212**. The negative terminal of the battery string **416** may be directly connected to the negative terminal **212**.
(35) The positive terminal of the battery string **416** is connected to the negative terminal of the battery string **412** such that the battery strings **412** and **416** are connected in series when switch **444** is closed. The switch **444** can be opened to disconnect the positive terminal of the battery string **416** from the negative terminal of the battery string **412**. The positive terminal of the battery string **412** is connected to the negative terminal of the battery string **408** such that the battery strings **412** and **408** are connected in series when switch **448** is closed. The switch **448** can be opened to disconnect the positive terminal of the battery string **412** from the negative terminal of the battery string **408**.
(36) Switches **452**, **456**, and **460** respectively connect and disconnect the positive terminals of the battery strings **408**, **412**, and **416** to and from a first bus (e.g., 12 V bus) that is connected to the second positive terminal **214** of the battery **208**. Switch **464** connects and disconnects the positive terminal of the battery string **408** to and from a second bus (e.g., a 48 V bus) that is connected to the first positive terminal **210** of the battery **208**.
(37) The switch control module **240**, FIG. **2**, controls switching of the switches of each of the battery modules **224** (the set of switches). At any given time, the switch control module **240** may actuate the switches associated with a battery module such that the battery module is in an open (X) configuration, a series (S) configuration, or a parallel (P) configuration. FIG. **4** includes an example illustration of the battery module **404** in the open (X) configuration. When a battery module is in the open (X) configuration, all the battery strings of the battery module are disconnected from both the first positive terminal **210** and the second positive terminal **214**.
(38) Referring back to FIG. **2**, each of the battery modules **224** also includes a plurality of temperature sensors, such as temperature sensors **250-1**, . . . , **250-**N. For example, one battery temperature sensor may be provided for each battery string and measure a temperature of that battery string.
(39) FIG. **5** shows a schematic diagram **500** for a diagnostic circuit for a cell of the MODACS, in an illustrative embodiment. The diagnostic circuit includes an isolated programmable load **502** and the cell, which is represented by an equivalent circuit model **504**. Although only one cell or equivalent circuit model **504** is shown in the schematic diagram **500**, it is understood that the diagnostic system can include a plurality of cells wired in series to form a string of the MODACS. The isolated programmable load **502** can be a resistor or a transistor, such as an isolated field effect transistor (FET). In other embodiments, the isolated FET is an additional FET that is dedicated to heat generation for diagnostic purposes. The MODACS is connected to an external load **522** that is external to the MODACS which can use current from the MODACS for various power operations. An auxiliary power module (APM) or generator **524** is also external to the MODACS.
(40) In various embodiments, the equivalent circuit model **504** includes an internal battery or internal voltage source **506**, a first resistor **508**, a first RC pair **510**, and a second RC pair **512**, all in series with each other. The cell (i.e., equivalent circuit model **504**) is electrically in parallel with the isolated FET. A microprocessor **514** is coupled to the isolated FET and applies a voltage at the gate of the isolated FET to produce a current in the isolated FET thereby generating heat. Current can also flow through the equivalent circuit model **504**, generating heat at the cell through conduction. Thus, heat at the equivalent circuit model **504** can occur due to heat produced at the isolated FET (and received at the cell via convection) as well as heat produced by the flow of current in the cell (i.e., through conduction). The convection heat raises the temperature inside the battery. In various embodiments, the heat can be used to maintain a temperature of the cell or to raise the temperature of the cell to within a suitable temperature range at which the cell performs at an optimal or desired

level.

(41) The diagnostic circuit includes a voltage sensor **516** for measuring a voltage across the isolated programmable load **502**. Although not shown in FIG. **5**, the MODACS also includes additional sensors for measuring voltage, current and temperature at the cell.

(42) In an embodiment, the microprocessor **514** generates a voltage pattern at the gate of the isolated FET to cause the isolated FET to generate heat. The pulsed voltage pattern can be designed to perform various diagnoses on the state of health (SOH) of the cell. An illustrative pulsed voltage pattern is shown by mini-sweep pulse pattern **520** shown in FIG. **5**. Time is shown along the abscissa and charging rate is shown along the coordinate axis. The mini-sweep pulse pattern **520** provides a quick identifiable pulse pattern that can be used for heating and subsequent diagnosis of the state of health (SOH) of the cell. The mini-sweep pulse pattern **520** includes multiple changes in charging rate and discharging rate, with nearly immediate changes between different charging rate levels. The mini-sweep pulse pattern **520** is shown as operating the isolated FET in a saturated region. In other embodiments, the mini-sweep pulse pattern **520** can operate the FET in a non-saturated region.

(43) The mini-sweep pulse pattern **520** is one of many possible sweep patterns that can be used to generate heat at the cell and to extract parameters of the equivalent circuit model **504** for the cell. By applying the mini-sweep pulse pattern **520** for diagnostic heating during operation of a cell, the processor can measure and/or update parameters of the equivalent circuit model **504** and compare the parameters to the same parameters of a model of an ideal cell. The ideal cell can be a simulation of the cell. The model of the ideal cell can be a model for a new cell or a healthy cell operating under a given condition, such as at a selected temperature, selected state of charge, etc. In various embodiments, models of a normal or healthy cell at various stages of its life can be stored in a database. The equivalent circuit model **504** can be compared to a stored model that corresponds to the age of the equivalent circuit model. In various embodiments, the models can be stored in a array defined by the aged of the cell and operating temperature of the cell. Interpolation or extrapolation can be applied to the stored models to produce an interpolated model that corresponds to the age of the cell and its operating temperature. A state of health of the cell can be determined by comparing the parameter(s) from the equivalent circuit model **504** to the parameter(s) from the model of the ideal cell under the same conditions. Once the state of health has been determined, the processor can calculate an optimal SOC and/or operating temperature and can operate the cell withing the optimal SOC and/or operating temperature or to meet a required power requirement. The diagnosis and setting the setting point can be performed at the microprocessor **514** or at a remote processor.

(44) In an embodiment, the parameter of the equivalent circuit model **504** is a time constant. By heating the FET and through the pulsed voltage pattern, the RC voltage across the RC pairs of the equivalent circuit model **504** exhibit a decay rate having a calculatable time constant (τ=RC). RC voltage can thus be measured to determine the decay rate of the equivalent circuit model **504**. The decay rate can be compared to a decay rate for an ideal cell, healthy cell or to safety standards to evaluate or estimate the state of health of the cell. An optimal operating set point for the battery or cell can then be determined based on the diagnosed state of health of the cell.

(45) In another embodiment, the voltage that occurs at the cell in response to the applied pulsed voltage pattern can be compared to a voltage of the ideal cell under the same pulsed voltage pattern. A comparison of the voltages indicates whether the voltage of the ECM sags or overshoot the voltage of the ideal cell under the same charging rates and discharging rates. If the voltage of the equivalent circuit model **504** is within a selected threshold of the voltage of the ideal cell, the cell is considered to have a SOH sufficient for power requirements of the cell. If the voltage sags or overshoots the voltage of the ideal model by an amount outside of the selected threshold, the cell is considered to have an SOH that is insufficient for power requirements.

(46) In various operations, current can be applied from the cell to the external load **522** to produce

a discharge power at the external load Heating at the cells can be prevent or reduce the amount of plating occurring at the cells due to current flow. The vehicle can control the external load to create heating and analyzable pulse patterns **526**. The current from the cell heats the cell during power discharge. Since the external load is external to the battery, any heat generated at the external load **522** does not enter into the MODACS and therefore does not heat the cell. Also, when the APM or generator **524** provides power to the external load **522**, there is no current through the cell. Thus, use of the APM or generator **524** produces no heating at the cell, either directly through conduction or indirectly through convection.

(47) FIG. **6** shows a flowchart **600** of a method for diagnosing a cell of the MODACS, in an illustrative embodiment. In box **602**, a string including the cell is selected from the MODACS and taken offline. In box **604**, a pulsed voltage pattern is applied to the isolated programmable load **502** to generate heat at the cell. In box **606**, voltage, current and temperature measurements are obtained at the cell in response to the pulsed voltage pattern. In box **608**, one or more parameters of the cell are determined from the voltage, current and temperature measurements. In box **610**, the one or more parameters of the cell (i.e., equivalent circuit model **504**) are compared to one or more parameters of a model of an ideal cell to determine a state of health (SOH) of the cell. In box **612**, a determination is made of whether the SOH of cell is sufficient for the cell to meet operating or power requirements. If the SOH is considered sufficient, the method proceeds to box **620**. In box **620**, the string is restored to online status.

(48) Returning to box **612**, if the SOH is insufficient, the method proceeds to box **614**. In box **614**, an operating parameter of the cell is adjusted so that the cell can meet the power requirements. For example, a performance of the cell can be improved by adjusting or raising a temperature of the cell within a given temperature range. Alternatively, an SOC of the cell can be adjusted. In box **616**, a check is made of the efficacy of adjusting the operating parameter. If it is not possible to adjust the operating parameter so that the cell meets power requirements, the method proceeds to box **618**. In box **618**, an alert signal is sent to indicate the condition of the cell. The cell is kept offline. Returning to box **616**, if the operating parameter can be adjusted to make the cell meet power requirements, the method proceeds to box **620**. In box **620**, the cell is placed back online.

(49) FIG. **7** shows a schematic diagram **700** illustrating a power system for generating heat at a cell of the MODACS. The power system includes strings **702_1**, . . . , **702**_N, with each string including a first power path FET **704_1**, . . . , **704**_N, respectively, and a second power path FET **706_1**, . . . , **706**_N, respectively. The power system also includes isolated FETs **708_1**, . . . **708**_N. The isolated FETs **708_1**, . . . , **708**-N are isolated programmable loads, such as the isolated programmable load **502** (FET) shown in FIG. **5**. In an embodiment, each isolated FET **708_1**, . . . **708**_N is associated with a corresponding string **702_1**, . . . **702**_N. For example, isolated FET **1208_1** is associated with string **702_1**, etc.

(50) Microprocessor **514** controls heat generation at the strings **7021**, . . . **702**_N, either individually or together. In one mode, the microprocessor **514** can control operation of a power path FET in order to control heating at its corresponding string, as indicated by loop **710**. For example, the microprocessor **514** can provide the pulsed voltage pattern to the first power path FET **704_1** to generate heat at string **702_1**. In another mode, the microprocessor **514** can control operation of an isolated FET to control heating at is corresponding string, as shown by loop **712**. For example, the microprocessor **514** can provide the pulsed voltage pattern to isolated FET **708_1** to generate heat at string **702_1**.

(51) The microprocessor **514** can take the string under test offline for diagnosis while the remaining strings are left online. Once the string under test is found to be healthy or an operating point of the string is changed based on the diagnosis, the microprocessor **514** can place the string under test back online.

(52) The terms “a” and “an” do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item. The term “or” means “and/or” unless clearly indicated otherwise

by context. Reference throughout the specification to “an aspect”, means that a particular element (e.g., feature, structure, step, or characteristic) described in connection with the aspect is included in at least one aspect described herein, and may or may not be present in other aspects. In addition, it is to be understood that the described elements may be combined in any suitable manner in the various aspects.

(53) When an element such as a layer, film, region, or substrate is referred to as being “on” another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being “directly on” another element, there are no intervening elements present.

(54) Unless specified to the contrary herein, all test standards are the most recent standard in effect as of the filing date of this application, or, if priority is claimed, the filing date of the earliest priority application in which the test standard appears.

(55) Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of skill in the art to which this disclosure belongs.

(56) While the above disclosure has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from its scope. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiments disclosed, but will include all embodiments falling within the scope thereof.

Claims

1. A method of operating a Multiple Output Dynamically Adjustable Capacity System (MODACS), comprising: applying a voltage to a load and to an equivalent circuit model of a cell of the MODACS, the equivalent circuit model being electrically parallel to the load, wherein applying the voltage to the load generates heat at the equivalent circuit model, thereby affecting a temperature of the equivalent circuit model; measuring a parameter of the equivalent circuit model in response to the heat generated by the load; comparing the parameter of the equivalent circuit model to an ideal model of the cell to determine a state of health of the cell; and controlling an operating parameter of the cell based on the state of heath of the cell to meet a power requirement for the cell.

2. The method of claim 1, wherein the load is at least one of: (i) an isolated programmable load; (ii) a field effect transistor (FET) internal to the MODACS; (iii) a FET powered by the cell; and (iv) a FET isolated from the cell.

3. The method of claim 2, wherein the isolated programmable load is a FET and the voltage is a pulsed voltage pattern applied at a gate of the FET.

4. The method of claim 1, wherein applying the voltage to the load generates a current through the cell.

5. The method of claim 4, further comprising generating the heat at the by at least one of: (i) convection via applying the voltage at the load; and (ii) conduction via passing the current through the cell.

6. The method of claim 1, further comprising comparing the parameter of the equivalent circuit model to the parameter of an ideal model of the cell determine a set point for operating the MODACS based on the state of health.

7. The method of claim 6, wherein the equivalent circuit model includes an RC pair and the parameter is a decay rate of the RC pair.

8. The method of claim 1, wherein controlling the operating parameter of the cell further comprises performing at least one of: (i) draining the cell; and (ii) operating the MODACS at a determined SOC set point for the cell.

9. The method of claim 1, further comprising taking the cell offline and applying the voltage to the load when the cell is offline.
10. A Multiple Output Dynamically Adjustable Capacity System (MODACS), comprising: a cell; a load in thermal communication with the cell; an equivalent model of the cell that is electrically parallel to the load; a processor configured to: apply a voltage to the load and to the equivalent circuit model, wherein applying the voltage to the load generates heat at the cell, thereby affecting a temperature of the equivalent circuit model of the cell; measure a parameter of the equivalent circuit model in response to the heat generated by the load; and compare the parameter of the equivalent circuit model to an ideal model of the cell to determine a state of health of the cell; and control an operation of the cell based on the state of heath of the cell to meet a power requirement for the cell.
11. The MODACS of claim 10, wherein the load is at least one of: (i) an isolated programmable load; (ii) a field effect transistor (FET) internal to the MODACS; (iii) a FET powered by the cell; and (iv) a FET isolated from the cell.
12. The MODACS of claim 11, wherein the isolated programmable load is a FET and the voltage is a pulsed voltage pattern applied at a gate of the FET.
13. The MODACS of claim 10, wherein applying the voltage to the load generates a current through the cell.
14. The MODACS of claim 13, wherein the heat is generated at the cell by at least one of: (i) convection via applying the voltage at the load; and (ii) conduction via passing the current through the cell.
15. The MODACS of claim 10, wherein the processor is further configured to compare the parameter of the equivalent circuit model to the parameter of an ideal model of the cell to determine a set point for operating the MODACS based on the state of health.
16. The MODACS of claim 10, wherein the equivalent circuit model includes an RC pair and the parameter is a decay rate of the RC pair.
17. The MODACS of claim 10, wherein the processor is further configured to control the operating parameter of the cell to perform at least one of: (i) draining the cell; and (ii) operating the MODACS at a determined SOC set point for the cell.
18. The MODACS of claim 10, wherein the processor is further configured to take the cell offline and apply the voltage to the load when the cell is offline.
19. The method of claim 3, wherein applying the voltage further comprises applying the pulsed voltage pattern to operate the field effect transistor in a saturated region.
20. The MODACS of claim 12, wherein the pulsed voltage pattern operates the field effect transistor in a saturated region.