

EXTERNAL COOLING SYSTEM AND METHOD FOR SEGMENTED BATTERY MODULES MOUNTED WITHIN AN ELECTRIC VEHICLE

TECHNICAL CONTRIBUTION

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The present disclosure relates to cooling systems and methods for battery cells of electric vehicles. More particularly, the present disclosure relates to a system and method for individualized cooling of segmented battery modules mounted within an electric vehicle.

10 BACKGROUND

Use of battery power for larger electric vehicles, such as locomotives, is an emerging field of development with great potential for reducing infrastructure expenses. Overhead electric lines or third rail electric power systems are not required when employing battery power for locomotives. Legacy train rails designed for diesel-powered locomotives, for instance, can be used for battery powered locomotives without any retrofit of the train rails. The use of battery power for these large electric vehicles, however, introduces additional challenges resulting from the charging and discharging of the battery cells.

20 The larger electric vehicles are generally recharged at a power source that includes a power supply. Electric buses, trolleys, and locomotives often connect to the power supply of the power source via a pantograph arrangement on the roof of the electric vehicle. The power supply can also be received via umbilical cables between the power source and the electric vehicle.

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To reduce downtime of the equipment, the battery cells of the electric vehicles can be charged in a short time frame with a higher current, such as a 3C current that is three times the discharge current of the electric vehicle during motorized operation. Following Joule's first law, heat generation from the charging current in a battery cell during charging with three times the maximum discharge current is roughly proportional to the square of the current passing through the battery cell, not considering other losses in the system. Hence charging with three times the maximum discharge current for a battery cell may result in roughly nine times greater heat generation during charging.

The higher current loads during charging sessions can quickly generate heat that drives the temperature of the charging battery cells outside their preferred operating temperature tolerances. If the preferred temperature ranges of the battery cells are not maintained, the battery lifespan can be shortened and the battery charging capacity can be diminished.

Particularly during charging, battery cell cooling is a critical design requirement for larger electric vehicles. The preferred charging temperature range for battery cells is typically narrower than the preferred discharging temperature range for the same battery. Lithium-based battery cells, for instance, have a preferred charging temperature range from about 0°C to 45°C and a preferred discharging temperature range from –20°C to 60°C. Nickel-based battery cells similarly have a preferred charging temperature range from about 0°C to 45°C and a preferred discharging temperature range from –20°C to 65°C.

The cooling of battery cells in larger electric vehicle is addressed by U.S. Patent Application No. 2020/0331504A1 entitled “Track - Guided Vehicle, Arrangement for Cooling an Energy Storage Device of the Track - Guided Vehicle, and Method for Controlling the Arrangement” published on 22 October 2020. In this publication’s disclosed design, a coolant is driven through an energy storage device of the electric vehicle to cool the battery cells. The design includes a temperature sensor within the energy storage device for monitoring the temperature of the battery cells and controlling the cooling system.

Battery cells for larger electric vehicles are often mounted within battery modules. Each battery module may include its own set of sensors in data communication with an enclosed battery management unit (BMU). Sensors for a battery module can include a temperature sensor, a current sensor, and a voltage sensor. The sensor information feedback from the BMU of each battery module is particularly useful in controlling a charging session for a larger electric vehicles with tens of battery modules. The state of charge (SOC), voltage requirements, and/or current requirements of each of the battery modules may differ due to the design, age, and operating history of the battery module.

Each BMU can transmit sensor information to a master battery management system (MBMS). The MBMS can in turn be in data communication with a controller housed in the electric

vehicle. The MBMS can also have its own sensors, such as temperature sensors, voltage sensors, and current sensors. Data communication between each BMU and the MBMS as well as data communication between the MBMS and the controller of the electric vehicle can be accomplished via an assortment of proprietary communication protocols or standardized communication protocols. The data communication can be accomplished via wired or via wireless communication.

What is needed in the art is a segmented cooling architecture that leverages both the sensor information collected by modern BMUs and addresses the individual cooling needs of each of the battery modules within an electric vehicle. In the background art, differences in temperature (and other measurable conditions of the battery modules) are not utilized by the cooling system. In the background art, for instance, equal flow of coolant is sent to each battery module of the electric vehicle regardless of the temperature differences between the battery modules.

SUMMARY

In its most general form, the internal cooling system and method for segmented battery modules within an electric vehicle provides individualized coolant flow to each of a plurality of energy storage devices housed in the electric vehicle. Each energy storage device includes a heat exchanger coupled in thermal conductivity with a segmented battery module. The segmented battery module includes battery cells and sensors. The heat exchanger includes an HE flow controller. Individual sensor information for each energy storage device is collected via the BMU of each segmented battery module. The internal SCC uses this individual sensor information to calculate the HE flow rate of coolant pumped through each energy storage device's heat exchanger to cool the battery cells of the energy storage device. Coolant delivered to the heat exchangers is cooled by an internal cooling unit during each charging session, and can also be cooled by the internal cooling unit during motorized operation of the electric vehicle.

A first embodiment of the internal cooling invention is an internal cooling system for a plurality of segmented battery modules. The system comprises: (a) a plurality of energy storage devices, each energy storage device including a heat exchanger and one of the segmented battery modules; (b) an electrical connection; (c) an internal cooling unit with an ICU inlet and an ICU outlet; (d) a pair of coolant trunks; and (e) an internal segmented cooling controller (SCC)

including a set of parameters. The internal SCC is configured to directly or indirectly receive the sensor information collected by the BMU of each energy storage device wirelessly or by wire via the BMU connector of the energy storage device, the sensor information includes at least temperature information measured by the at least one temperature sensor located within the segmented battery module of the energy storage device. The set of parameters include at least a preferred temperature range for the segmented battery module of each energy storage device. The internal SCC is configured to periodically: (1) calculate or recalculate an optimal range for the HE flow rate of the heat exchanger of each energy storage device; and (2) control by wire or wirelessly the HE flow rate of each energy storage device, via the direct or indirect data communication with the HE flow controller of the energy storage device, to maintain the HE flow rate within the optimal range. The optimal range is a function of: (a) the sensor information received by the internal SCC from the sensors of the energy storage device via the BMU of the energy storage device; and (b) the preferred temperature range for the energy storage device.

A second embodiment of the internal cooling invention is a computer-implemented internal cooling method for a plurality of segmented battery modules. The method comprises: (a) maintaining a plurality of energy storage devices, each energy storage device including a heat exchanger and one of the segmented battery modules; (b) maintaining an electrical connection; (c) maintaining an internal cooling unit with an ICU inlet and an ICU outlet; (d) maintaining a pair of coolant trunks; (e) maintaining an internal segmented cooling controller (SCC) including a set of parameters; (f) periodically employing the internal SCC to calculate or recalculate an optimal range for the HE flow rate of the heat exchanger of each energy storage device; and (g) controlling by wire or wirelessly the HE flow rate of each energy storage device, via the direct or indirect data communication with the HE flow controller of the energy storage device, to maintain the HE flow rate within the optimal range. The internal SCC is configured to directly or indirectly receive the sensor information collected by the BMU of each energy storage device wirelessly or by wire via the BMU connector of the energy storage device, the sensor information including at least temperature information measured by the at least one temperature sensor located within the segmented battery module of the energy storage device. The set of parameters include at least a preferred temperature range for the segmented battery module of each energy storage. The optimal range is a function of: (i) the sensor information

received by the internal SCC from the sensors of the energy storage device via the BMU of the energy storage device; and (ii) the preferred temperature range for the energy storage device.

In its most general form, the external cooling system and method for segmented battery modules within an electric vehicle provides individualized coolant flow to each of a plurality of energy storage devices housed in the electric vehicle. Each energy storage device includes a heat exchanger coupled in thermal conductivity with a segmented battery module. The segmented battery module includes battery cells and sensors. The heat exchanger includes an HE flow controller. Individual sensor information for each energy storage device is collected via the BMU of each segmented battery module. The charging SCC uses this individual sensor information to calculate the HE flow rate of coolant pumped through each energy storage device's heat exchanger to cool the battery cells of the energy storage device. Coolant delivered to the heat exchangers is cooled by an external cooling unit of a power source during each charging session.

A first embodiment of the external cooling invention is an external cooling system for a plurality of segmented battery modules. The system comprises an electric vehicle paired with a power source: (a) a plurality of energy storage devices housed in the electric vehicle, each energy storage device including a heat exchanger and one of the segmented battery modules; (b) an electrical connection housed in the electric vehicle; (c) a master battery management system (MBMS) housed in the electric vehicle; (d) an external cooling unit housed in the power source, the external cooling unit including an ECU inlet and an ECU outlet; (e) a pair of coolant trunks housed in the electric vehicle; and (f) a charging segmented cooling controller (SCC), the charging SCC including a set of parameters. During each charging session the charging SCC is configured to periodically: (1) calculate or recalculate an optimal range for the HE flow rate of the heat exchanger of each energy storage device; and (2) control by wire or wirelessly the HE flow rate of each energy storage device, via the direct or indirect data communication with the HE flow controller of the energy storage device, to maintain the HE flow rate within the optimal range. The optimal range is a function of: (a) the sensor information received by the charging SCC from the sensors of the energy storage device via the BMU of the energy storage device; and (b) the preferred temperature range for the energy storage device.

A second embodiment of the external cooling invention is a computer-implemented external cooling method for a plurality of segmented battery modules. The method comprises: (a) maintaining a plurality of energy storage devices in an electric vehicle, each energy storage device including a heat exchanger and one of the segmented battery modules; (b) maintaining an electrical connection in the electric vehicle; (c) maintaining a master battery management system (MBMS) in the electric vehicle; (d) maintaining an external cooling unit in a power source, the external cooling unit including an ECU inlet and an ECU outlet; (e) maintaining a pair of coolant trunks in the electric vehicle; (f) maintaining a charging segmented cooling controller (SCC), the charging SCC including a set of parameters; (g) commencing the charging session for one or more energy storage devices; (h) during the charging session, periodically employing the charging SCC to calculate or recalculate an optimal range for the HE flow rate of the heat exchanger of each energy storage device; and (i) during the charging session, controlling by wire or wirelessly the HE flow rate of each energy storage device, via the direct or indirect data communication with the HE flow controller of the energy storage device, to maintain the HE flow rate within the optimal range. The step of commencing the charging session includes: (i) connecting the master battery management system (MBMS) to the charging SCC; and (ii) connecting the electrical connection to one or more power supplies via one or more electrical connection connectors. The optimal range is a function of: (i) the sensor information received by the charging SCC from the sensors of the energy storage device via the BMU of the energy storage device; and (ii) the preferred temperature range for the energy storage device.

The segmented cooling architecture of the invention, whether employing an internal cooling unit or an external cooling unit, leverages the sensor information collected by each of the BMUs in the electric vehicle. With this sensor information, the SCC can prioritize the individual cooling needs of the segmented battery modules. The primary benefit of the invention is that the battery cells of individual segmented battery modules are sheltered from the effects of improper temperature control, which can damage the battery cells or shorten the battery cell life cycle.

A secondary benefit is that the internal cooling unit or external cooling unit can operate at a lower power rating when using the invention, because the coolant is specifically distributed to where it is most needed. This targeted approach reduces the requisite size of the cooling unit

and the amount of energy used by the cooling unit. A smaller and lower power cooling unit can be installed within the electric vehicle because the overall coolant production need is reduced due to the invention's targeted distribution of coolant.

5 A third benefit is achieved when using the external cooling unit design. As governed by Joule's first law, heat generation from the charging current in a battery cell is proportional to the square of the current passing through the battery cells, not considering other losses in the system. Charging current can often be two, three, or four times the maximum discharge current used during motorized operation of the electric vehicle. Hence, the heat generated within the battery
10 cells during a charging session can be, for instance, nine times greater than the heat generated during discharge of the battery cells (e.g., during motorized operation of the electric vehicle) if three times the maximum discharge current is undertaken. As a result, large quantities of coolant are mostly required at the location of the charging (e.g., at the power source when the electric vehicle is electrically connected to a power supply during a charging session), for
15 instance where the roughly 9x heat generation occurs during charging with three times the maximum discharge current.

During motorized operation of the electric vehicle, less expensive and lower power cooling means (such as ambient air cooling, forced air cooling, or air conditioning cooling) than water
20 cooling may suffice. Assuming a charging session with three times the maximum discharge current, the discharge current during motorized operation is only about one third the charging current, thus the heat generation during motorized operation is also one about one ninth the heat generated during an example charging session with three times the maximum discharge current. Also, during motorized operation of an electric vehicle, any single segmented battery
25 module with a high temperature can be quickly shut down without impacting the locomotion of the electric vehicle, as other segmented battery modules of lower temperature can be used to power the electric vehicle while the overheated segmented battery module is permitted to cool down.

30 With the use of an external cooling unit design, a robust cooling system can be housed at a power source. The expense of the robust cooling system can be amortized over its use to charge multiple electric vehicles each day of the year. Also, with use of an external cooling unit, the electric vehicle is spared the additional weight load, volumetric space, and expense of the

installation of an internal cooling unit within the electric vehicle. In place of a large internal cooling unit, the extra weight allocation and volumetric space can be allocated, for instance, to the installation of additional segmented battery modules within the electric vehicle to extend the travel distance of the electric vehicle between charging sessions.

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BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present disclosure are described herein with reference to the drawings in which:

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FIG. 1 is a block diagram representing an internal cooling system housed in a motorized electric vehicle, in electrical connection to a power supply of a power source during a charging session, in an embodiment of the invention.

15 **FIG. 2** is a block diagram representing the electrical and data communication connections of an internal cooling system housed in a motorized electric vehicle, in electrical connection to a power supply of a power source during a charging session, in an embodiment of the invention.

20 **FIG. 3** is a block diagram representing fluid connection of components along the segmented coolant pathway of an internal cooling system housed in a motorized electric vehicle, in an embodiment of the invention.

FIG. 4 is a block diagram representing an external cooling system split between a motorized electric vehicle and a power source, in an embodiment of the invention.

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FIG. 5 is a block diagram representing the electrical and data communication connections of an external cooling system split between a motorized electric vehicle and a power source, in an embodiment of the invention.

30 **FIG. 6A** is a block diagram representing fluid connection of components along the segmented coolant pathway passing through an external cooling unit, in an embodiment of the invention.

FIG. 6B is a block diagram representing fluid connection of components along the segmented coolant pathway passing through an internal cooling unit and an external-to-internal heat exchanger linked in thermal conductivity to an external cooling unit, in an embodiment of the invention.

5 **FIG. 6C** is a block diagram representing fluid connection of components along the segmented coolant pathway passing through both an internal cooling unit and an external cooling unit, in an embodiment of the invention.

10 **FIG. 7** is a flowchart of steps taken in a computer-implemented internal cooling method, in an embodiment of the invention.

FIG. 8 is a flowchart of steps taken in a computer-implemented external cooling method, in an embodiment of the invention.

15 **DETAILED DESCRIPTION**

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. The illustrative embodiments described in the detailed description, drawings and claims are not meant to be limiting. Other embodiments can be utilized, and other changes
20 can be made, without departing from the spirit or scope of the subject matter presented herein. Unless specified otherwise, the terms “comprising,” “comprise,” “including” and “include” used herein, and grammatical variants thereof, are intended to represent “open” or “inclusive” language such that they include recited elements but also permit inclusion of additional, un-recited elements. Data communication can be accomplished via wired or wireless means; data
25 communication can be implemented directly between components or indirectly between components.

FIG. 1 is a block diagram representing an internal cooling system housed in a motorized electric vehicle **1-00**, in electrical connection to a power supply **23** of a power source **20** during
30 a charging session, in an embodiment of the invention. The motorized electric vehicle **1-00** includes a plurality of energy storage devices **10**, a pair of coolant trunks **14C**, an internal cooling unit **14**, MBMS **15**, an internal segmented cooling controller (SCC) **16**, an electrical connection **17**, and at least one traction motor **18A** for driving wheels **18B**. The energy storage

device **10** includes an optional thermal interface **12** between a heat exchanger **11** and a segmented battery module **13**. The heat exchanger **11** includes an HE inlet **11A**, an HE outlet **11B**, an HE flow controller **11C**, and a plurality of HE passages **11D**. While illustrated in **FIG. 1** as a flow valve, the HE flow controller **11C** can be a flow valve, a variable speed drive (VSD) coolant pump, or a combination of the two. The HE flow controller **11C** is directly or indirectly controlled by the internal SCC **22** by wired or wireless communication to increase or decrease coolant flow through the segmented coolant pathways as needed. The HE flow controller **11C** is in wired or wireless data communication with the internal SCC **22**.

As illustrated in **FIG. 1**, the segmented battery module **13** includes: (i) a plurality of battery cells **13B** in electrical connection to an electrical connection connector **17A**; and (ii) a battery management unit (BMU) **13A** in data communication with a temperature sensor **13C**, a voltage sensor **13D**, and a current sensor **13E**. The internal SCC **16** includes a set of parameters. For simplicity in **FIG. 1**, just one energy storage device **10**, *01* of *N*, and its components are depicted.

FIG. 1 illustrates a segmented coolant pathway for an internal cooling system embodiment of the invention. For each energy storage device **10**, the segmented coolant pathway exits from the internal cooling unit **14** via the ICU outlet **14A**, through the cool trunk **14C-1** (not shown in **FIG. 1**, see **FIG. 3**) of the pair of coolant trunks **14C**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2** (not shown in **FIG. 1**, see **FIG. 3**) of the pair of coolant trunks **14C**, and back into the internal cooling unit **14** via the ICU inlet **14B**. The segmented coolant pathway passes through the HE flow controller **11C** of the energy storage device **10**. When coolant is pumped through each segmented coolant pathway, there is an HE flow rate through the HE flow controller **11C** of the energy storage device **10**, the HE flow controller **11C** can regulate this HE flow rate. In this embodiment, there is no flow of coolant between the motorized electric vehicle **1-00** and the power source **20**.

FIG. 1 illustrates data communication connections from the sensors (**13C**, **13E**, and **13E**) to the BMU **13A**, to the MBMS **15** wirelessly or by wire via the BMU connector **13F**, to the

internal SCC **16**. The internal SCC **16** is also in data communication with the internal cooling unit **14**.

FIG. 1 illustrates electrical power connections between: (i) the battery cells **13B** of each energy storage device **10** and the electrical connection **17** via the battery connector **13G** of the energy storage device **10**; (ii) the electrical connection **17** and the at least one traction motor **18A** driving the wheels **18B**; and (iii) the power supply **23** of the power source **20** and the electrical connection **17** via the electrical connection connector **17A**.

While not illustrated in **FIG. 1**, the invention can also be implemented as a power car. Power cars do not have traction motors **18A** but have wheels **18B**. Power cars include a power outlet that can be connected to a power inlet of a motorized electric vehicle **1-00** such as a locomotive.

FIG. 2 is a block diagram representing the electrical and data communication connections of an internal cooling system housed in a motorized electric vehicle **1-00**, in electrical connection to a power supply **23** of a power source **20** during a charging session, in an embodiment of the invention. **FIG. 2** depicts three energy storage device **10** ($01, 02 \dots N$), each with its own BMU **13A** ($\text{BMU}_{01}, \text{BMU}_{02} \dots \text{BMU}_N$). The battery cells **13B** of each energy storage device **10** are in electrical connection to the electrical connection **17**. The BMUs **13A** of each energy storage device **10** are in data communication with the MBMS **15**. The MBMS **15** is in data communication with the internal SCC **16**. The internal SCC **16** is in data communication with the internal cooling unit **14**. The electrical connection **17** is in electrical connection with the at least one traction motor **18A** which drives the wheels **18B** of the motorized electric vehicle **1-00**. The electrical connection **17** is in electrical connection to the power supply **23** of the power source **20** via the electrical connection connector **17A**, such as during a charging session. Not illustrated, for simplicity of the figure, is the data communication pathways, either wired or wireless, between the internal SCC **16** and each of the HE flow controllers **11C**.

FIG. 3 is a block diagram representing fluid connection of components along the segmented coolant pathway of an internal cooling system housed in a motorized electric vehicle **1-00**, in an embodiment of the invention. For each energy storage device **10**, the segmented coolant pathway exits from the internal cooling unit **14** via the ICU outlet **14A**, through the cool trunk **14C-1** of the pair of coolant trunks **14C**, through the HE inlet **11A** of the energy

storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2**, and back into the internal cooling unit **14** via the ICU inlet **14B**. The segmented coolant pathway passes through the HE flow controller **11C** of the energy storage device **10**. When coolant is

5 pumped through each segmented coolant pathway, there is an HE flow rate through the HE flow controller **11C** of the energy storage device **10**, the HE flow controller **11C** can regulate this HE flow rate. In this embodiment, there is no flow of coolant between the motorized electric vehicle **1-00** and the power source **20**. The block diagram of **FIG. 3** is also representative of the segmented coolant pathway of an internal cooling system housed in a

10 power car. While illustrated in **FIG. 3** as a flow valve, the HE flow controller **11C** can be a flow valve, a variable speed drive (VSD) coolant pump, or a combination of the two. The HE flow controller **11C** is directly or indirectly controlled by the internal SCC **22** to increase or decrease coolant flow through the segmented coolant pathways as needed. The HE flow controller **11C** is in wired or wireless data communication with the internal SCC **22**.

15 **FIG. 4** is a block diagram representing an external cooling system split between a motorized electric vehicle **1-00** and a power source **20**, in an embodiment of the invention. The motorized electric vehicle **1-00** includes a plurality of energy storage devices **10**, a pair of coolant trunks **14C**, a master battery management system (MBMS) **15**, an electrical connection **17**, and at

20 least one traction motor **18A** for driving wheels **18B**. The power source **20** includes an external cooling unit **21**, a charging segmented cooling controller (SCC) **22**, and a power supply **23**. The energy storage device **10** includes an optional thermal interface **12** between a heat exchanger **11** and a segmented battery module **13**, typically used with water cooling. The heat exchanger **11** includes an HE inlet **11A**, an HE outlet **11B**, an HE flow controller **11C**, and a

25 plurality of HE passages **11D**. While illustrated in **FIG. 4** as a flow valve, the HE flow controller **11C** can be a flow valve, a variable speed drive (VSD) coolant pump, or a combination of the two. The HE flow controller **11C** is directly or indirectly controlled by the charging SCC **22** to increase or decrease coolant flow through the segmented coolant pathways as needed.

30 As illustrated in **FIG. 4**, the HE flow controller **11C** is in wired or wireless data communication with the charging SCC **22** via an HE flow connector **11E**. In alternative embodiments detailed in **FIGs. 6B** and **6C**, control of the HE flow controller **11C** could be dictated by either the

charging SCC **22** mounted in the power source **20**, an internal SCC **16** mounted inside the electric vehicle, or a combination of the two.

As illustrated in **FIG. 4**, the segmented battery module **13** includes: (i) a plurality of battery cells **13B** in electrical connection to an electrical connection connector **17A**; and (ii) a battery management unit (BMU) **13A** in data communication with a temperature sensor **13C**, a voltage sensor **13D**, and a current sensor **13E**. The charging SCC **22** includes a charging segmented cooling controller (SCC) **22** including a set of parameters. For simplicity in **FIG. 4**, just one energy storage device **10**, of N , and its components are depicted.

FIG. 4 illustrates a segmented coolant pathway for an external cooling system embodiment of the invention. For each energy storage device **10**, the segmented coolant pathway exits from the external cooling unit **21** of the power source **20** via the ECU outlet **21A**, through the cool trunk **14C-1** (not illustrated in **FIG. 4**, see **FIG. 6A**) of the pair of coolant trunks **14C**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2** (not illustrated in **FIG. 4**, see **FIG. 6A**) of the pair of coolant trunks **14C**, and back into the external cooling unit **21** of the power source **20** via the ECU inlet **21B**. The segmented coolant pathway passes through the HE flow controller **11C** of the energy storage device **10**. When coolant is pumped through each segmented coolant pathway, there is an HE flow rate through the HE flow controller **11C** of the energy storage device **10**, the HE flow controller **11C** can regulate this HE flow rate. In this embodiment, there is a flow of coolant between the motorized electric vehicle **1-00** and the power source **20**.

FIG. 4 illustrates data communication connections from the sensors (**13C**, **13D**, and **13E**) to the BMU **13A**, to the MBMS **15** wirelessly or by wire via the BMU connector **13F**, to the charging SCC **22** via the MBMS connector **15A**. The charging SCC **22** is also in data communication with the external cooling unit **21**.

FIG. 4 illustrates electrical power connections between: (i) the battery cells **13B** of each energy storage device **10** and the electrical connection **17** via the battery connector **13G** of the energy storage device **10**; (ii) the electrical connection **17** and the at least one traction motor

18A driving the wheels 18B; and (iii) the power supply 23 of the power source 20 and the electrical connection 17 via the electrical connection connector 17A.

FIG. 5 is a block diagram representing the electrical and data communication connections of an external cooling system split between a motorized electric vehicle 1-00 and a power source 20, in an embodiment of the invention. FIG. 5 depicts three energy storage device 10 (01, 02 . . . N), each with its own BMU 13A (BMU₀₁, BMU₀₂ . . . BMU_N). The battery cells 13B of each energy storage device 10 are in electrical connection to the electrical connection 17. The BMUs 13A of each energy storage device 10 are in data communication with the MBMS 15. The MBMS 15 is in data communication with the charging SCC 22. The charging SCC 22 is in data communication with the external cooling unit 21. The electrical connection 17 is in electrical connection with the at least one traction motor 18A which drives the wheels 18B of the motorized electric vehicle 1-00. The electrical connection 17 is in electrical connection to the power supply 23 of the power source 20 via the electrical connection connector 17A, such as during a charging session. Not illustrated, for simplicity of the figure, is the data communication pathways, either wired or wireless, between the charging SCC 22 (or any internal SCC 16 as in the embodiments of FIG. 6B and 6C) and each of the HE flow controllers 11C.

FIG. 6A is a block diagram representing fluid connection of components along the segmented coolant pathway of an external cooling system passing through an external cooling unit 21, in an embodiment of the invention. The segmented coolant pathway exits from the external cooling unit 21 via the ECU outlet 21A, through the cool trunk 14C-1 of the pair of coolant trunks 14C, through the HE inlet 11A of the energy storage device 10, through the HE passages 11D of the energy storage device 10, through the HE outlet 11B of the energy storage device 10, through the warm trunk 14C-2, and back into the external cooling unit 21 of the power source 20 via the ECU inlet 21B. The segmented coolant pathway passes through the HE flow controller 11C of the energy storage device 10. When coolant is pumped through each segmented coolant pathway, there is an HE flow rate through the HE flow controller 11C of the energy storage device 10, the HE flow controller 11C can regulate this HE flow rate. In this embodiment, there is a flow of coolant between the motorized electric vehicle 1-00 and the power source 20. The block diagram of FIG. 6A is also representative of the segmented coolant pathway of an external cooling system housed in a power car.

The **FIG. 6A** embodiment does not include an internal cooling unit **14**. As illustrated in **FIGs. 6B** and **6C**, discussed below, embodiments of the invention can optionally include an internal cooling unit **14** to cool the segmented battery modules **13** during motorized operation of the electric vehicle and/or during charging sessions.

FIG. 6B is a block diagram representing fluid connection of components along the segmented coolant pathway of an external cooling system passing through an internal cooling unit **14** and an external-to-internal heat exchanger **14D** linked in thermal conductivity to an external cooling unit **21**, in an embodiment of the invention. For each energy storage device **10**, the segmented coolant pathway exits from the internal cooling unit **14** via the ICU outlet **14A**, through the cool trunk **14C-1** of the pair of coolant trunks **14C**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2**, and back into the internal cooling unit **14** via the ICU inlet **14B**. The segmented coolant pathway passes through the HE flow controller **11C** of the energy storage device **10**. When coolant is pumped through each segmented coolant pathway, there is an HE flow rate through the HE flow controller **11C** of the energy storage device **10**, the HE flow controller **11C** can regulate this HE flow rate. In this embodiment, there is a flow of coolant between the motorized electric vehicle **1-00** and the power source **20**. The block diagram of **FIG. 6B** is also representative of the segmented coolant pathway of an external cooling system housed in a power car.

As illustrated in **FIG. 6B**, the coolant in the segmented coolant pathway is additionally cooled in an external-to-internal heat exchanger **14D**. The external-to-internal heat exchanger **14D** received a second coolant pathway from an external cooling unit **21** in the power source **20**. The second coolant pathway exits from the external cooling unit **21** via the ECU outlet **21A**, passes through the external-to-internal heat exchanger **14D**, and returns to the external cooling unit **21** via the ECU inlet **21B**. The coolant of the segmented coolant pathway does not mix with the coolant of the second coolant pathway. This coolant separation enables use of different coolants between the electric vehicle's internal cooling unit **14** and the power source's external cooling unit **21**. Such separation also avoids issues arising from use of polluted coolant, corrosive coolant, or unfiltered coolant.

FIG. 6C is a block diagram representing fluid connection of components along the segmented coolant pathway of an external cooling system passing through both an internal cooling unit **14** and an external cooling unit **21**, in an embodiment of the invention. The segmented coolant pathway exits from the external cooling unit **21** via the ECU outlet **21A**, through the cool trunk **14C-1** of the pair of coolant trunks **14C**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2**, into the internal cooling unit **14** via the ICU inlet **14B**, out of the internal cooling unit **14** via the ICU outlet **14A**, and back into the external cooling unit **21** of the power source **20** via the ECU inlet **21B**. The segmented coolant pathway passes through the HE flow controller **11C** of the energy storage device **10**. When coolant is pumped through each segmented coolant pathway, there is an HE flow rate through the HE flow controller **11C** of the energy storage device **10**, the HE flow controller **11C** can regulate this HE flow rate. In this embodiment, there is a flow of coolant between the motorized electric vehicle **1-00** and the power source **20**. The block diagram of **FIG. 6C** is also representative of the segmented coolant pathway of an external cooling system housed in a power car.

While illustrated in **FIGs. 6A, 6B, and 6C** as a flow valve, the HE flow controller **11C** can be a flow valve, a variable speed drive (VSD) coolant pump, or a combination of the two. As illustrated in these figures, the HE flow controller **11C** is directly or indirectly controlled by the charging SCC **22** during the charging session to increase or decrease coolant flow through the segmented coolant pathways as needed. The HE flow controller **11C** is in wired or wireless data communication with the charging SCC **22**. Note that the charging SCC **22** (if housed in the electric vehicle) can be used to control the internal cooling unit **14** and HE flow controllers **11C** to cool the segmented battery modules **13** during motorized operation of the electric vehicle; alternatively, an internal SCC **16** can be added to the electric vehicle to control the internal cooling unit **14** and HE flow controllers **11C** to cool the segmented battery modules **13** during motorized operation of the electric vehicle.

FIG. 7 is a flowchart **7-00** of steps taken in a computer-implemented internal cooling method, in an embodiment of the invention. Steps **7-01** to **7-04** are listed below.

- 7-01** collect sensor information from the sensors of each energy storage device **10**, the sensor information transmitted from each sensor to the BMU **13A** of the energy storage device **10**, to the MBMS wirelessly or by wire via the BMU connector **13F** of the energy storage device **10**, to the internal SCC **16**
- 7-02** access the parameters for each energy storage device **10** from the set of parameters stored in the internal SCC **16**
- 7-03** employ the internal SCC **16** to calculate or recalculate the optimal range for the HE flow rate through the HE flow controller **11C** of each energy storage device **10** employing either a thermal model for the energy storage device **10** and/or a control loop to maintain segmented battery module **13** of the energy storage device **10** within a preferred temperature range
- 7-04** adjust the HE flow rate through the HE flow controller **11C** to within the optimal range, collect sensor information, and repeat calculations

FIG. 8 is a flowchart of steps taken in a computer-implemented external cooling method, in an embodiment of the invention. Steps **8-01** to **8-09** are listed below.

- 8-01** park electric vehicle at power source **20** and connect: (1) ECU inlet **21B** and ECU outlet **21A** to coolant trunks **14C**; (2) the charging SCC **22** to the MBMS via the MBMS connector **15A**; and (3) the power supply **23** to electrical connection **17** via the electrical connection connector **17A**
- 8-02** collect sensor information from sensors, transmit sensor information to the MBMS wirelessly or by wire via the BMU connector **13F**, and receive sensor information at the charging SCC **22** via the MBMS connector **15A**
- 8-03** access the parameters for each energy storage device **10** from the set of parameters stored in the charging SCC **22**
- 8-04** commence charging session to charge the battery cells **13B** of each energy storage device **10**
- 8-05** calculate or recalculate the optimal range for the HE flow rate through the HE flow controller **11C** employing either a thermal model or a control loop to maintain segmented battery module **13** within a preferred temperature range

- 8-06** adjust the HE flow rate through the HE flow controller **11C** within the optimal range, collect sensor information, and repeat calculations until completion of charging session
- 8-07** end charging session
- 8-08** disconnect ECU inlet **21B** and ECU outlet **21A** from coolant trunks **14C**, charging SCC **22** from MBMS connector **15A**, and power supply **23** from electrical connection connector **17A**
- 8-09** move electric vehicle out from power source **20**, optionally cooling the segmented battery modules **13** during motorized operation of the electric vehicle using an internal cooling unit **14** as controlled by an internal SCC **16**

In its most general form, the internal cooling system and method for segmented battery modules **13** within an electric vehicle provides individualized coolant flow to each of a plurality of energy storage devices **10** housed in an electric vehicle. Each energy storage device **10** includes a heat exchanger **11** coupled in thermal conductivity with a segmented battery module **13**. The segmented battery module **13** includes battery cells **13B** and sensors (**13C**, **13D**, and **13E**). The heat exchanger **11** includes an HE flow controller **11C**. Individual sensor information for each energy storage device **10** is collected via the BMU **13A** of each segmented battery module **13**. The internal SCC **16** uses this individual sensor information to calculate the HE flow rate of coolant pumped through each energy storage device's **10** heat exchanger **11** to cool the battery cells **13B** of the energy storage device **10**. Coolant delivered to the heat exchangers **11** is cooled by an internal cooling unit **14** during each charging session, and can also be cooled by the internal cooling unit **14** during motorized operation of the electric vehicle.

A first embodiment of the internal cooling invention is an internal cooling system for a plurality of segmented battery modules **13**. The system comprises: (a) a plurality of energy storage devices **10**, each energy storage device **10** including a heat exchanger **11** and one of the segmented battery modules **13**; (b) an electrical connection **17**; (c) an internal cooling unit **14** with an ICU inlet **14B** and an ICU outlet **14A**; (d) a pair of coolant trunks **14C**; and (e) an internal segmented cooling controller (SCC) **16** including a set of parameters. The heat exchanger **11** of each energy storage device **10** includes: (1) an HE flow controller **11C** for controlling flow of coolant through the heat exchanger **11**; (2) an HE inlet **11A** for receiving

the coolant into a plurality of HE passages **11D** within the heat exchanger **11**; and (3) an HE outlet **11B** for discharging coolant from the HE passages **11D** of the heat exchanger **11**. The segmented battery module **13** of each energy storage device **10** includes: (1) a plurality of battery cells **13B** in electrical connection with an electrical connection connector **17A**; (2) a battery management module (BMU) **13A** in data communication with a plurality of sensors, the sensors including at least one temperature sensor **13C** located within the segmented battery module **13** and the BMU **13A** configured to collect sensor information from the sensors; and (3) a BMU connector **13F** in data communication with the BMU **13A**. The electrical connection **17** is in electrical connection to the battery connector **13G** of each of the energy storage devices **10**. The electrical connection **17** is in electrical connection with one or more electrical connection connectors **17A**. Each of the one or more electrical connection connectors **17A** are connectable to one of one or more power supplies **23** of a power source **20** during a charging session for one or more of the energy storage devices **10**. The pair of coolant trunks **14C** includes: (1) a cool trunk **14C-1** with cooled coolant received from the internal cooling unit **14** via the ICU outlet **14A**; and (2) a warm trunk **14C-2** with warmed coolant directed into the internal cooling unit **14** via the ICU inlet **14B**. The cool trunk **14C-1** is in fluid connection with each of the HE inlets **11A** of the energy storage devices **10**. The warm trunk **14C-2** is in fluid connection with each of the HE outlets **11B** of the energy storage devices **10**. A segmented coolant pathway between the internal cooling unit **14** and each heat exchanger **11** is established for each energy storage device **10**, the segmented coolant pathway exiting from the internal cooling unit **14** via the ICU outlet **14A**, through the cool trunk **14C-1**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2**, and back into the internal cooling unit **14** via the ICU inlet **14B**. The segmented coolant pathway passes through the HE flow controller **11C** of the energy storage device **10**. The segmented coolant pathway has an HE flow rate through the HE flow controller **11C** of the energy storage device **10**. The segmented coolant pathway established for each energy storage device **10** has an HE flow rate regulated by the HE flow controller **11C**. The internal SCC **16** is in direct or indirect data communication with: (1) the internal cooling unit **14**; (2) the HE flow controller **11C** of each energy storage device **10**; and (3) the BMU **13A** of the segmented battery module **13** of each energy storage device **10** via the BMU connector **13F** of the energy storage device **10**. The internal SCC **16** is configured to directly or indirectly receive the sensor information collected by the BMU **13A** of each energy storage device **10** wirelessly or by wire

via the BMU connector **13F** of the energy storage device **10**, the sensor information includes at least temperature information measured by the at least one temperature sensor **13C** located within the segmented battery module **13** of the energy storage device **10**. The set of parameters include at least a preferred temperature range for the segmented battery module **13** of each energy storage device **10**. The internal SCC **16** is configured to periodically: (1) calculate or recalculate an optimal range for the HE flow rate of the heat exchanger **11** of each energy storage device **10**; and (2) control by wire or wirelessly the HE flow rate of each energy storage device **10**, via the direct or indirect data communication with the HE flow controller **11C** of the energy storage device **10**, to maintain the HE flow rate within the optimal range. The optimal range is a function of: (a) the sensor information received by the internal SCC **16** from the sensors of the energy storage device **10** via the BMU **13A** of the energy storage device **10**; and (b) the preferred temperature range for the energy storage device **10**.

In an alternative embodiment of the first embodiment of the internal cooling invention, the internal SCC **16** employs a control loop to: (a) adjust a power rating delivered to the internal cooling unit **14**; (b) according to the temperature information from the temperature sensor **13C** of the segmented battery module **13** of each of the energy storage devices **10**, prioritize delivery of coolant to at least one of the energy storage devices **10**; and (c) adjust the HE flow rate of coolant through one or more of the HE flow controllers **11C**;

In an alternative embodiment of the first embodiment of the internal cooling invention, the plurality of sensors in the segmented battery module **13** of each energy storage device **10** further include a current sensor **13E** configured to measure and transmit current information of the battery cells **13B** of the segmented battery module **13** to the internal SCC **16** via the BMU **13A** of the energy storage device **10**. Also, the set of parameters includes a thermal model for each energy storage device **10**. Further, the internal SCC **16** is further configured to calculate or recalculate for each energy storage device **10**: (i) a heat generation estimate for the energy storage device **10** from the thermal model of the energy storage device **10**, the current information for the energy storage device **10**, and the preferred temperature range for the energy storage device **10**; and (ii) the optimal range for the HE flow rate of the energy storage device **10** to counteract the heat generation estimate for the energy storage device **10**.

In an alternative embodiment of the first embodiment of the internal cooling invention, the coolant is a fluid, water, a gas, or air.

5 In an alternative embodiment of the first embodiment of the internal cooling invention: (a) the system further includes a master battery management system (MBMS) **15**; and (b) wired or wireless data communication between the internal SCC **16** and the BMU connector **13F** of each energy storage device **10** is routed through the MBMS **15**.

10 In an alternative embodiment of the first embodiment of the internal cooling invention: (a) the heat exchanger **11** and the segmented battery module **13** of each energy storage device **10** are paired in thermal conductivity via a thermal interface **12**; (b) the heat exchanger **11** for each energy storage device **10** includes a heat sink conforming to at least one outer surface area of the segmented battery module **13** of the energy storage device **10**; and (c) the thermal interface
15 **12** between the heat sink and the segmented battery module **13** of each energy storage device **10** is a compressible thermally conductive material or a thermally conductive paste. The heat sink of each energy storage device **10** can comprise an aluminum shell enclosing the HE passages **11D** of the energy storage device **10**.

20 Conduction of heat from the battery cells **13B** to the outer surface area of the segmented battery module **13** can be increased by use of heat conducting frame components within the segmented battery module **13**. Use of multiple heat sinks is also beneficial, such as a first heat sink on a top surface of the segmented battery module **13** and a second heat sink on the bottom surface of the segmented battery module **13**. Use of a compressible thermally conductive material or a thermally conductive paste is beneficial because air gaps between the segmented battery
25 module **13** and the heat sink act as a heat insulation layer. It is useful to have many HE passages **11D** within the heat sink to cool a wider surface area of the segmented battery module **13**.

In an alternative embodiment of the first embodiment of the internal cooling invention, the system is housed in an electric vehicle. The electric vehicle can be a motorized electric vehicle
30 **1-00** or a power car. If a motorized electric vehicle **1-00**, the motorized vehicle includes a vehicle control system and at least one traction motor **18A** in electrical connection with the electrical connection **17**, wherein operation of the at least one traction motor **18A** is controlled by the vehicle control system and the internal SCC **16** is in data communication with the vehicle

control system. In a motorized vehicle, the internal SCC **16** can be configured to download or link to either: (i) an itinerary map detailing at least one of a speed map, an incline grade map, a travel distance, and a travel time; or (ii) a vehicle dashboard detailing at least one of a present speed of the motorized electric vehicle **1-00**, a present electrical current load of the at least one traction motor **18A** of the motorized electric vehicle **1-00**, and a present incline of the motorized electric vehicle **1-00**. If the electric vehicle is a power car, then: (a) the power car includes one or more power outlets in electrical connection to the electrical connection **17** of the system; and (b) the one or more power outlets are connectable to one or more power inlets of a motorized electric vehicle **1-00**.

A second embodiment of the internal cooling invention is a computer-implemented internal cooling method for a plurality of segmented battery modules **13**. The method comprises: (a) maintaining a plurality of energy storage devices **10**, each energy storage device **10** including a heat exchanger **11** and one of the segmented battery modules **13**; (b) maintaining an electrical connection **17**; (c) maintaining an internal cooling unit **14** with an ICU inlet **14B** and an ICU outlet **14A**; (d) maintaining a pair of coolant trunks **14C**; (e) maintaining an internal segmented cooling controller (SCC) **16** including a set of parameters; (f) periodically employing the internal SCC **16** to calculate or recalculate an optimal range for the HE flow rate of the heat exchanger **11** of each energy storage device **10**; and (g) controlling by wire or wirelessly the HE flow rate of each energy storage device **10**, via the direct or indirect data communication with the HE flow controller **11C** of the energy storage device **10**, to maintain the HE flow rate within the optimal range. The heat exchanger **11** of each energy storage device **10** includes: (1) an HE flow controller **11C** for controlling flow of coolant through the heat exchanger **11**; (2) an HE inlet **11A** for receiving the coolant into a plurality of HE passages **11D** within the heat exchanger **11**; and (3) an HE outlet **11B** for discharging coolant from the HE passages **11D** of the heat exchanger **11**. The segmented battery module **13** of each energy storage device **10** includes: (1) a plurality of battery cells **13B** in electrical connection with an electrical connection connector **17A**; (2) a battery management module (BMU) **13A** in data communication with a plurality of sensors, the sensors including at least one temperature sensor **13C** located within the segmented battery module **13** and the BMU **13A** configured to collect sensor information from the sensors; and (3) a BMU connector **13F** in data communication with the BMU **13A**. The electrical connection **17** is in electrical connection to the battery connector **13G** of each of the energy storage devices **10**. The electrical connection **17** is in

electrical connection with one or more electrical connection connectors **17A**. Each of the one or more electrical connection connectors **17A** are connectable to one of one or more power supplies **23** of a power source **20** during a charging session for one or more of the energy storage devices **10**. The pair of coolant trunks **14C** includes: (1) a cool trunk **14C-1** with cooled coolant received from the internal cooling unit **14** via the ICU outlet **14A**; and (2) a warm trunk **14C-2** with warmed coolant directed into the internal cooling unit **14** via the ICU inlet **14B**. The cool trunk **14C-1** is in fluid connection with each of the HE inlets **11A** of the energy storage devices **10**. The warm trunk **14C-2** is in fluid connection with each of the HE outlets **11B** of the energy storage devices **10**. A segmented coolant pathway between the internal cooling unit **14** and each heat exchanger **11** is established for each energy storage device **10**, the segmented coolant pathway exiting from the internal cooling unit **14** via the ICU outlet **14A**, through the cool trunk **14C-1**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2**, and back into the internal cooling unit **14** via the ICU inlet **14B**. The segmented coolant pathway passing through the HE flow controller **11C** of the energy storage device **10**. The segmented coolant pathway having an HE flow rate through the HE flow controller **11C** of the energy storage device **10**. The segmented coolant pathway established for each energy storage device **10** has an HE flow rate regulated by the HE flow controller **11C**. The internal SCC **16** is in direct or indirect data communication with: (1) the internal cooling unit **14**; (2) the HE flow controller **11C** of each energy storage device **10**; and (3) the BMU **13A** of the segmented battery module **13** of each energy storage device **10** via the BMU connector **13F** of the energy storage device **10**. The internal SCC **16** is configured to directly or indirectly receive the sensor information collected by the BMU **13A** of each energy storage device **10** wirelessly or by wire via the BMU connector **13F** of the energy storage device **10**, the sensor information including at least temperature information measured by the at least one temperature sensor **13C** located within the segmented battery module **13** of the energy storage device **10**. The set of parameters include at least a preferred temperature range for the segmented battery module **13** of each energy storage. The optimal range is a function of: (i) the sensor information received by the internal SCC **16** from the sensors of the energy storage device **10** via the BMU **13A** of the energy storage device **10**; and (ii) the preferred temperature range for the energy storage device **10**.

In an alternative embodiment of the second embodiment of the internal cooling invention, the internal SCC **16** employs a control loop to: (a) adjust a power rating delivered to the internal cooling unit **14**; (b) according to the temperature information from the temperature sensor **13C** of the segmented battery module **13** of each of the energy storage devices **10**, prioritize delivery of coolant to at least one of the energy storage devices **10**; and (c) adjust the HE flow rate of coolant through one or more of the HE flow controllers **11C**.

In an alternative embodiment of the second embodiment of the internal cooling invention, the plurality of sensors in the segmented battery module **13** of each energy storage device **10** further include a current sensor **13E** configured to measure and transmit current information of the battery cells **13B** of the segmented battery module **13** to the internal SCC **16** via the BMU **13A** of the energy storage device **10**. Also, the set of parameters includes a thermal model for each energy storage device **10**. Further, the step of periodically employing the internal SCC **16** to calculate or recalculate the optimal range includes calculating or recalculating for each energy storage device **10**: (i) a heat generation estimate for the energy storage device **10** from the thermal model of the energy storage device **10**, the current information for the energy storage device **10**, and the preferred temperature range for the energy storage device **10**; and (ii) the optimal range for the HE flow rate of the energy storage device **10** to counteract the heat generation estimate for the energy storage device **10**.

In an alternative embodiment of the second embodiment of the internal cooling invention, the coolant is a fluid, water, a gas, or air.

In an alternative embodiment of the second embodiment of the internal cooling invention: (a) the system further includes a master battery management system (MBMS) **15**; and (b) wired or wireless data communication between the internal SCC **16** and the BMU connector **13F** of each energy storage device **10** is routed through the MBMS **15**.

In an alternative embodiment of the second embodiment of the internal cooling invention: (a) the heat exchanger **11** for each energy storage device **10** includes a heat sink conforming to at least one outer surface area of the segmented battery module **13** of the energy storage device **10**; and (b) the thermal interface **12** between the heat sink and the segmented battery module **13** of each energy storage device **10** is a compressible thermally conductive material or a

thermally conductive paste. The heat sink of each energy storage device **10** can comprise an aluminum shell enclosing the HE passages **11D** of the energy storage device **10**.

5 In an alternative embodiment of the second embodiment of the internal cooling invention, the method is implemented by an electric vehicle. The electric vehicle can be a motorized electric vehicle **1-00** or a power car. If a motorized electric vehicle **1-00**: (a) the motorized electric vehicle **1-00** includes a vehicle control system and at least one traction motor **18A** in electrical connection with the electrical connection **17**; (b) operation of the at least one traction motor **18A** is controlled by the vehicle control system; and (c) the internal SCC **16** is in data
10 communication with the vehicle control system. The internal SCC **16** is configured to download or link to at least one of: (i) an itinerary map detailing at least one of a speed map, an incline grade map, a travel distance, and a travel time; and (ii) a vehicle dashboard detailing at least one of a present speed of the motorized electric vehicle **1-00**, a present electrical current load of the at least one traction motor **18A** of the motorized electric vehicle **1-00**, and a present
15 incline of the motorized electric vehicle **1-00**.

In an alternative embodiment of the second embodiment of the internal cooling invention: (a) the electric vehicle is a power car including one or more power outlets in electrical connection to the electrical connection **17** of the system; and (b) the one or more power outlets are
20 connectable to one or more power inlets of a motorized electric vehicle **1-00**.

In its most general form, the external cooling system and method for segmented battery modules **13** within an electric vehicle provides individualized coolant flow to each of a plurality of energy storage devices **10** housed in an electric vehicle. Each energy storage device **10**
25 includes a heat exchanger **11** coupled in thermal conductivity with a segmented battery module **13**. The segmented battery module **13** includes battery cells **13B** and sensors (**13C**, **13D**, and **13E**). The heat exchanger **11** includes an HE flow controller **11C**. Individual sensor information for each energy storage device **10** is collected via the BMU **13A** of each segmented battery module **13**. The charging SCC **22** uses this individual sensor information to calculate
30 the HE flow rate of coolant pumped through each energy storage device's **10** heat exchanger **11** to cool the battery cells **13B** of the energy storage device **10**. Coolant delivered to the heat exchangers **11** is cooled by an external cooling unit **21** of a power source **20** during each charging session.

An external cooling system and method for segmented battery modules **13** mounted within an electric vehicle is a system and method enabling individualized coolant flow to each of a plurality of energy storage devices **10** housed in an electric vehicle. Each energy storage device

5 **10** includes a heat exchanger **11** coupled in thermal conductivity with a segmented battery module **13**. The segmented battery module **13** includes battery cells **13B** and sensors (**13C**, **13D**, and **13E**). The heat exchanger **11** includes an HE flow controller **11C**. Individual sensor information for each energy storage device **10** is collected via the BMU **13A** of each segmented battery module **13**. The charging SCC **22** uses this individual sensor information to calculate

10 the HE flow rate of coolant pumped through each energy storage device's **10** heat exchanger **11** to cool the battery cells **13B** of the energy storage device **10**. Coolant delivered to the heat exchangers **11** is cooled by an external cooling unit **21** of a power source **20** during each charging session.

15 A first embodiment of the external cooling invention is an external cooling system for a plurality of segmented battery modules **13**. The system comprises an electric vehicle paired with a power source **20**: (a) a plurality of energy storage devices **10** housed in the electric vehicle, each energy storage device **10** including a heat exchanger **11** and one of the segmented battery modules **13**; (b) an electrical connection **17** housed in the electric vehicle; (c) a master

20 battery management system (MBMS) **15** housed in the electric vehicle; (d) an external cooling unit **21** housed in the power source **20**, the external cooling unit **21** including an ECU inlet **21B** and an ECU outlet **21A**; (e) a pair of coolant trunks **14C** housed in the electric vehicle; and (f) a charging segmented cooling controller (SCC) **22**, the charging SCC **22** including a set of parameters. The heat exchanger **11** of each energy storage device **10** includes: (1) an HE flow

25 controller **11C** for controlling flow of coolant through the heat exchanger **11**; (2) an HE inlet **11A** for receiving the coolant into a plurality of HE passages **11D** within the heat exchanger **11**; and (3) an HE outlet **11B** for discharging coolant from the HE passages **11D** of the heat exchanger **11**. The segmented battery module **13** of each energy storage device **10** includes:

30 (1) a plurality of battery cells **13B** in electrical connection with an electrical connection connector **17A**; (2) a battery management module (BMU) **13A** in data communication with a plurality of sensors, the sensors including at least one temperature sensor **13C** located within the segmented battery module **13** and the BMU **13A** configured to collect sensor information from the sensors; and (3) a BMU connector **13F** in data communication with the BMU **13A**.

The electrical connection **17** is in electrical connection to the battery connector **13G** of each of the energy storage devices **10**. The electrical connection **17** is in electrical connection with one or more electrical connection connectors **17A**. Each of the one or more electrical connection connectors **17A** are connectable to one of one or more power supplies **23** of the power source **20** during each of a plurality of charging sessions for one or more of the energy storage devices **10** during each charging session. The MBMS **15** is in data communication with the BMU **13A** of each energy storage device **10** wirelessly or by wire via the BMU connector **13F** of the energy storage device **10**. The pair of coolant trunks **14C** includes: (1) a cool trunk **14C-1** for receiving cooled coolant; and (2) a warm trunk **14C-2** for discharging warmed coolant. The cool trunk **14C-1** is in fluid connection with each of the HE inlets **11A** of the energy storage devices. The warm trunk **14C-2** is in fluid connection with each of the HE outlets **11B** of the energy storage devices. A segmented coolant pathway between the external cooling unit **21** and each heat exchanger **11** is established for each energy storage device **10**. The segmented coolant pathway passes through the HE flow controller **11C** of the energy storage device **10**. The segmented coolant pathway has an HE flow rate through the HE flow controller **11C** of the energy storage device **10**. The segmented coolant pathway established for each energy storage device **10** has an HE flow rate regulated by the HE flow controller **11C**. During each charging session the charging SCC **22** is in direct or indirect data communication by wire or wirelessly with: (1) the external cooling unit **21**; (2) the HE flow controller **11C** of each energy storage device **10**; (3) the MBMS **15**; and (4) the BMU **13A** of the segmented battery module **13** of each energy storage device **10** via the MBMS **15** and the BMU connector **13F** of the energy storage device **10**. During each charging session the charging SCC **22** is configured to directly or indirectly receive the sensor information collected by the BMU **13A** of each energy storage device **10** wirelessly or by wire via the BMU connector **13F** of the energy storage device **10**, the sensor information including at least temperature information measured by the at least one temperature sensor **13C** located within the segmented battery module **13** of the energy storage device **10**. The set of parameters include at least a preferred temperature range for the segmented battery module **13** of each energy storage device **10**. During each charging session the charging SCC **22** is configured to periodically: (1) calculate or recalculate an optimal range for the HE flow rate of the heat exchanger **11** of each energy storage device **10**; and (2) control by wire or wirelessly the HE flow rate of each energy storage device **10**, via the direct or indirect data communication with the HE flow controller **11C** of the energy storage device **10**, to maintain the HE flow rate within the optimal range. The optimal range is a

function of: (a) the sensor information received by the charging SCC **22** from the sensors of the energy storage device **10** via the BMU **13A** of the energy storage device **10**; and (b) the preferred temperature range for the energy storage device **10**.

- 5 In an alternative embodiment of the first embodiment of the external cooling invention, the charging SCC **22** is housed in the electric vehicle or, alternatively, in the power source **20**.

In an alternative embodiment of the first embodiment of the external cooling invention: (a) the cool trunk **14C-1** receives cooled coolant from the external cooling unit **21** via the ECU outlet
10 **21A**; (b) the warm trunk **14C-2** discharges warmed coolant into the external cooling unit **21** via the ECU inlet **21B**; and (c) wherein the segmented coolant pathway for each energy storage device **10** exits from the external cooling unit **21** via the ECU outlet **21A**, through the cool trunk **14C-1**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage
15 device **10**, through the warm trunk **14C-2**, and back into the external cooling unit **21** via the ECU inlet **21B**.

In an alternative embodiment of the first embodiment of the external cooling invention, the system further comprises an external-to-internal heat exchanger **14D** and an internal cooling
20 unit **14**. The internal cooling unit **14** includes an ICU inlet **14B** and an ICU outlet **14A**. The cool trunk **14C-1** receives cooled coolant from the internal cooling unit **14** via the ICU outlet **14A** after the coolant passes through the external-to-internal heat exchanger **14D**. The warm trunk **14C-2** discharges warmed coolant into the internal cooling unit **14** via the ICU inlet **14B**. The segmented coolant pathway for each energy storage device **10** exits from the internal
25 cooling unit **14** via the ICU outlet **14A**, through the external-to-internal heat exchanger **14D**, through the cool trunk **14C-1** of the pair of coolant trunks **14C**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2**, and back into the internal cooling unit **14** via the ICU inlet **14B**. A second coolant pathway exits
30 from the external cooling unit **21** via the ECU outlet **21A**, passes through the external-to-internal heat exchanger **14D**, and returns to the external cooling unit **21** via the ECU inlet **21B**. This embodiment can optionally be configured such that: (a) the charging SCC **22** is housed in the electric vehicle; (b) the internal cooling unit **14** is in data communication with the

charging SCC **22**; and (c) the charging SCC **22** is configured to control coolant flow through each of the energy storage devices **10** during motorized operation of the electric vehicle. This embodiment can alternatively optionally be configured such that: (a) the system further comprises an internal segmented coolant controller (SCC) **16** housed in the electric vehicle; (b) the charging SCC **22** is housed in the power source **20**; (c) the internal cooling unit **14** is in data communication with the internal SCC **16**; and (d) the internal SCC **16** is configured to control coolant flow through each of the energy storage devices **10** during motorized operation of the electric vehicle.

In an alternative embodiment of the first embodiment of the external cooling invention, the system further comprises an internal cooling unit **14**. The cool trunk **14C-1** receives cooled coolant from the external cooling unit **21** via the ECU outlet **21A**. The warm trunk **14C-2** discharges warmed coolant into the internal cooling unit **14** via the ICU inlet **14B**. The segmented coolant pathway for each energy storage device **10** exits from the external cooling unit **21** via the ECU outlet **21A**, through the cool trunk **14C-1**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2**, into the internal cooling unit **14** via the ICU inlet **14B**, out of the internal cooling unit **14** via the ICU outlet **14A**, and back into the external cooling unit **21** via the ECU inlet **21B**. This embodiment can optionally be configured such that: (a) the charging SCC **22** is housed in the electric vehicle; (b) the internal cooling unit **14** is in data communication with the charging SCC **22**; and (c) the charging SCC **22** is configured to control coolant flow through each of the energy storage devices **10** during motorized operation of the electric vehicle. This embodiment can alternatively optionally be configured such that: (a) the system further comprises an internal segmented coolant controller (SCC) housed in the electric vehicle; (b) the charging SCC **22** is housed in the power source **20**; (c) the internal cooling unit **14** is in data communication with the internal SCC **16**; and (d) the internal SCC **16** is configured to control coolant flow through each of the energy storage devices **10** during motorized operation of the electric vehicle.

In an alternative embodiment of the first embodiment of the external cooling invention, the charging SCC employs a control loop to: (a) adjust a power rating delivered to the external cooling unit **21**; (b) according to the temperature information from the temperature sensor **13C**

of the segmented battery module **13** of each of the energy storage devices **10**, prioritize delivery of coolant to at least one of the energy storage devices **10**; and (c) adjust the HE flow rate of coolant through one or more of the HE flow controllers **11C**.

5 In an alternative embodiment of the first embodiment of the external cooling invention, the plurality of sensors in the segmented battery module **13** of each energy storage device **10** further include a current sensor **13E** configured to measure and transmit current information of the battery cells **13B** of the segmented battery module **13** to the charging SCC via the BMU **13A** of the energy storage device **10**. The set of parameters includes a thermal model for each
10 energy storage device **10**. The calculation or recalculation by the charging SCC of the optimal range for each energy storage device **10** includes calculation or recalculation of: (i) a heat generation estimate for the energy storage device **10** from the thermal model of the energy storage device **10**, the current information for the energy storage device **10**, and the preferred temperature range for the energy storage device **10**; and (ii) the optimal range for the HE flow
15 rate of the energy storage device **10** to counteract the heat generation estimate for the energy storage device **10**.

In an alternative embodiment of the first embodiment of the external cooling invention, the coolant is a fluid, water, a gas, or air.

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In an alternative embodiment of the first embodiment of the external cooling invention: (a) the heat exchanger **11** and the segmented battery module **13** of each energy storage device **10** are paired in thermal conductivity via a thermal interface **12**; (b) the heat exchanger **11** for each energy storage device **10** includes a heat sink conforming to at least one outer surface area of
25 the segmented battery module **13** of the energy storage device **10**; and (c) the thermal interface **12** between the heat sink and the segmented battery module **13** of each energy storage device **10** is a compressible thermally conductive material or a thermally conductive paste. The heat sink of each energy storage device **10** can comprise an aluminum shell enclosing the HE passages **11D** of the energy storage device **10**.

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In an alternative embodiment of the first embodiment of the external cooling invention: (a) the electric vehicle is a motorized electric vehicle **1-00** including a vehicle control system and at

least one traction motor **18A** in electrical connection with the electrical connection **17**; and (b) operation of the at least one traction motor **18A** is controlled by the vehicle control system.

In an alternative embodiment of the first embodiment of the external cooling invention: (a) the electric vehicle is a power car including one or more power outlets in electrical connection to the electrical connection **17**; and (b) the one or more power outlets are connectable to one or more power inlets of a motorized electric vehicle **1-00**.

A second embodiment of the external cooling invention is a computer-implemented external cooling method for a plurality of segmented battery modules **13**. The method comprises: (a) maintaining a plurality of energy storage devices **10** in an electric vehicle, each energy storage device **10** including a heat exchanger **11** and one of the segmented battery modules **13**; (b) maintaining an electrical connection **17** in the electric vehicle; (c) maintaining a master battery management system (MBMS) **15** in the electric vehicle; (d) maintaining an external cooling unit **21** in a power source **20**, the external cooling unit **21** including an ECU inlet **21B** and an ECU outlet **21A**; (e) maintaining a pair of coolant trunks **14C** in the electric vehicle; (f) maintaining a charging segmented cooling controller (SCC) **22**, the charging SCC **22** including a set of parameters; (g) commencing the charging session for one or more energy storage devices **10**; (h) during the charging session, periodically employing the charging SCC **22** to calculate or recalculate an optimal range for the HE flow rate of the heat exchanger **11** of each energy storage device **10**; and (i) during the charging session, controlling by wire or wirelessly the HE flow rate of each energy storage device **10**, via the direct or indirect data communication with the HE flow controller **11C** of the energy storage device **10**, to maintain the HE flow rate within the optimal range. The heat exchanger **11** of each energy storage device **10** includes: (1) an HE flow controller **11C** for controlling flow of coolant through the heat exchanger **11**; (2) an HE inlet **11A** for receiving the coolant into a plurality of HE passages **11D** within the heat exchanger **11**; and (3) an HE outlet **11B** for discharging coolant from the HE passages **11D** of the heat exchanger **11**. The segmented battery module **13** of each energy storage device **10** includes: (1) a plurality of battery cells **13B** in electrical connection with an electrical connection connector **17A**; (2) a battery management module (BMU) **13A** in data communication with a plurality of sensors, the sensors including at least one temperature sensor **13C** located within the segmented battery module **13** and the BMU **13A** configured to collect sensor information from the sensors; and (3) a BMU connector **13F** in data communication

with the BMU **13A**. The electrical connection **17** is in electrical connection to the battery connector **13G** of each of the energy storage devices **10**. The electrical connection **17** is in electrical connection with one or more electrical connection connectors **17A**. Each of the one or more electrical connection connectors **17A** are connectable to one of one or more power supplies **23** of the power source **20** during a charging session for one or more of the energy storage devices **10**. The MBMS **15** is in data communication with the BMU **13A** of each energy storage device **10** wirelessly or by wire via the BMU connector **13F** of the energy storage device **10**. The pair of coolant trunks **14C** includes: (1) a cool trunk **14C-1** for receiving cooled coolant; and (2) a warm trunk **14C-2** for discharging warmed coolant. The cool trunk **14C-1** is in fluid connection with each of the HE inlets **11A** of the energy storage devices. The warm trunk **14C-2** is in fluid connection with each of the HE outlets **11B** of the energy storage devices. A segmented coolant pathway between the external cooling unit **21** and each heat exchanger **11** is established for each energy storage device **10**. The segmented coolant pathway passes through the HE flow controller **11C** of the energy storage device **10**. The segmented coolant pathway has an HE flow rate through the HE flow controller **11C** of the energy storage device **10**. The segmented coolant pathway established for each energy storage device **10** has an HE flow rate regulated by the HE flow controller **11C**. During each charging session, the charging SCC **22** is in direct or indirect data communication by wire or wirelessly with: (1) the external cooling unit **21**; (2) the HE flow controller **11C** of each energy storage device **10**; (3) the MBMS **15**; and (4) the BMU **13A** of the segmented battery module **13** of each energy storage device **10** via the MBMS **15** and the BMU connector **13F** of the energy storage device **10**. During each charging session the charging SCC **22** is configured to directly or indirectly receive the sensor information collected by the BMU **13A** of each energy storage device **10** wirelessly or by wire via the BMU connector **13F** of the energy storage device **10**, the sensor information including at least temperature information measured by the at least one temperature sensor **13C** located within the segmented battery module **13** of the energy storage device **10**. The set of parameters include at least a preferred temperature range for the segmented battery module **13** of each energy storage device **10**. The step of commencing the charging session includes: (i) connecting the MBMS **15** to the charging SCC **22**; and (ii) connecting the electrical connection **17** to one or more power supplies **23** via one or more electrical connection connectors **17A**. The optimal range is a function of: (i) the sensor information received by the charging SCC **22** from the sensors of the energy storage device **10**

via the BMU **13A** of the energy storage device **10**; and (ii) the preferred temperature range for the energy storage device **10**.

5 In an alternative embodiment of the second embodiment of the external cooling invention, the charging SCC **22** is maintained in the electric vehicle or, alternatively, in the power source **20**.

10 In an alternative embodiment of the second embodiment of the external cooling invention: (a) the cool trunk **14C-1** receives cooled coolant from the external cooling unit **21** via the ECU outlet **21A**; (b) the warm trunk **14C-2** discharges warmed coolant into the external cooling unit **21** via the ECU inlet **21B**; and (c) wherein the segmented coolant pathway for each energy storage device **10** exits from the external cooling unit **21** via the ECU outlet **21A**, through the cool trunk **14C-1**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2**, and back into the external cooling unit **21** via the
15 ECU inlet **21B**.

In an alternative embodiment of the second embodiment of the external cooling invention, the method further comprises maintaining an external-to-internal heat exchanger **14D** and an internal cooling unit **14**. The internal cooling unit **14** includes an ICU inlet **14B** and an ICU
20 outlet **14A**. The cool trunk **14C-1** receives cooled coolant from the internal cooling unit **14** via the ICU outlet **14A** after the coolant passes through the external-to-internal heat exchanger **14D**. The warm trunk **14C-2** discharges warmed coolant into the internal cooling unit **14** via the ICU inlet **14B**. The segmented coolant pathway for each energy storage device **10** exits from the internal cooling unit **14** via the ICU outlet **14A**, through the external-to-internal heat
25 exchanger **14D**, through the cool trunk **14C-1** of the pair of coolant trunks **14C**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2**, and back into the internal cooling unit **14** via the ICU inlet **14B**. A second coolant pathway exits from the external cooling unit **21** via the ECU outlet **21A**, passes through
30 the external-to-internal heat exchanger **14D**, and returns to the external cooling unit **21** via the ECU inlet **21B**. This embodiment can further optionally be configured such that: (a) the charging SCC **22** is maintained in the electric vehicle; (b) the internal cooling unit **14** is in data communication with the charging SCC **22**; and (c) the charging SCC **22** is configured to control

coolant flow through each of the energy storage devices **10** during motorized operation of the electric vehicle. Alternatively, this embodiment can further optionally maintain an internal segmented coolant controller (SCC), where: (a) the charging SCC **22** is maintained in the power source **20**; (b) the internal cooling unit **14** is in data communication with the internal SCC **16**; and (c) the internal SCC **16** is configured to control coolant flow through each of the energy storage devices **10** during motorized operation of the electric vehicle.

In an alternative embodiment of the second embodiment of the external cooling invention, the method further comprises maintaining an internal cooling unit **14**. The cool trunk **14C-1** receives cooled coolant from the external cooling unit **21** via the ECU outlet **21A**. The warm trunk **14C-2** discharges warmed coolant into the internal cooling unit **14** via the ICU inlet **14B**. The segmented coolant pathway for each energy storage device **10** exits from the external cooling unit **21** via the ECU outlet **21A**, through the cool trunk **14C-1**, through the HE inlet **11A** of the energy storage device **10**, through the HE passages **11D** of the energy storage device **10**, through the HE outlet **11B** of the energy storage device **10**, through the warm trunk **14C-2**, into the internal cooling unit **14** via the ICU inlet **14B**, out of the internal cooling unit **14** via the ICU outlet **14A**, and back into the external cooling unit **21** via the ECU inlet **21B**. This embodiment can further optionally be configured such that: (a) the charging SCC **22** is maintained in the electric vehicle; (b) the internal cooling unit **14** is in data communication with the charging SCC **22**; and (c) the charging SCC **22** is configured to control coolant flow through each of the energy storage devices **10** during motorized operation of the electric vehicle. Alternatively, this embodiment can further optionally maintain an internal segmented coolant controller (SCC), where: (a) the charging SCC **22** is maintained in the power source **20**; (b) the internal cooling unit **14** is in data communication with the internal SCC **16**; and (c) the internal SCC **16** is configured to control coolant flow through each of the energy storage devices **10** during motorized operation of the electric vehicle.

In an alternative embodiment of the second embodiment of the external cooling invention, the charging SCC employs a control loop to: (a) adjust a power rating delivered to the external cooling unit **21**; (b) according to the temperature information from the temperature sensor **13C** of the segmented battery module **13** of each of the energy storage devices **10**, prioritize delivery of coolant to at least one of the energy storage devices **10**; and (c) adjust the HE flow rate of coolant through one or more of the HE flow controllers **11C**.

In an alternative embodiment of the second embodiment of the external cooling invention, the plurality of sensors in the segmented battery module **13** of each energy storage device **10** further include a current sensor **13E** configured to measure and transmit current information of the battery cells **13B** of the segmented battery module **13** to the charging SCC via the BMU **13A** of the energy storage device **10**. Also, the set of parameters includes a thermal model for each energy storage device **10**. Further, the step of periodically employing the charging SCC to calculate or recalculate the optimal range includes calculating or recalculating for each energy storage device **10**: (i) a heat generation estimate for the energy storage device **10** from the thermal model of the energy storage device **10**, the current information for the energy storage device **10**, and the preferred temperature range for the energy storage device **10**; and (ii) the optimal range for the HE flow rate of the energy storage device **10** to counteract the heat generation estimate for the energy storage device **10**.

In an alternative embodiment of the second embodiment of the external cooling invention, the coolant is a fluid, water, a gas, or air.

In an alternative embodiment of the second embodiment of the external cooling invention: (a) the heat exchanger **11** and the segmented battery module **13** of each energy storage device **10** are paired in thermal conductivity via a thermal interface **12**; (b) the heat exchanger **11** for each energy storage device **10** includes a heat sink conforming to at least one outer surface area of the segmented battery module **13** of the energy storage device **10**; and (c) the thermal interface **12** between the heat sink and the segmented battery module **13** of each energy storage device **10** is a compressible thermally conductive material or a thermally conductive paste. The heat sink of each energy storage device **10** can comprise an aluminum shell enclosing the HE passages **11D** of the energy storage device **10**.

In an alternative embodiment of the second embodiment of the external cooling invention: (a) the electric vehicle is a motorized electric vehicle **1-00** including a vehicle control system and at least one traction motor **18A** in electrical connection with the electrical connection **17**; and (b) operation of the at least one traction motor **18A** is controlled by the vehicle control system.

In an alternative embodiment of the second embodiment of the external cooling invention: (a) the electric vehicle is a power car including one or more power outlets in electrical connection to the electrical connection **17**; and (b) the one or more power outlets are connectable to one or more power inlets of a motorized electric vehicle **1-00**.

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While various aspects and embodiments have been disclosed herein, it will be apparent that various other modifications and adaptations of the invention will be apparent to the person skilled in the art after reading the foregoing disclosure without departing from the spirit and scope of the invention and it is intended that all such modifications and adaptations come within

10 the scope of the appended claims. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit of the invention being indicated by the appended claims.

CLAIMS

Claim 1 A cooling system for individualized cooling of a plurality of segmented battery modules, the system comprising an electric vehicle comprising one of a locomotive having at least one traction motor and a power car for the locomotive; and a power source paired with and externally disposed relative to the locomotive or the power car, wherein the system further comprises:

- (a) a plurality of energy storage devices housed in the electric vehicle, each individual energy storage device including a heat exchanger and one of the segmented battery modules in thermal conductivity with each other,
 - (i) wherein the heat exchanger of each individual energy storage device includes:
 - (1) an HE flow controller comprising a variable speed drive (VSD) coolant pump for controlling flow of coolant through the heat exchanger;
 - (2) an HE inlet for receiving the coolant into a plurality of HE passages within the heat exchanger; and
 - (3) an HE outlet for discharging coolant from the HE passages of the heat exchanger; and
 - (ii) wherein the segmented battery module of each energy storage device includes:
 - (1) a plurality of battery cells in electrical connection with an electrical connection connector;
 - (2) a battery management module (BMU) in data communication with a plurality of sensors, the sensors including at least one temperature sensor located within the segmented battery module and the BMU configured to collect sensor information from the sensors; and
 - (3) a BMU connector in wired or wireless data communication with the BMU;
- (b) an electrical connection housed in the electric vehicle,
 - (i) wherein the electrical connection is in electrical connection to the battery connector of each of the energy storage devices;
 - (ii) wherein the electrical connection is in electrical connection with one or more electrical connection connectors; and
 - (iii) wherein each of the one or more electrical connection connectors are connectable to one of one or more power supplies of the power source during each of a plurality of charging sessions for one or more of the energy storage devices during each charging session;

- (c) a master battery management system (MBMS) housed in the electric vehicle, wherein the MBMS is in wired or wireless data communication with the BMU of each energy storage device via the BMU connector of the energy storage device;
- (d) an external cooling unit housed in the power source, the external cooling unit including an ECU inlet and an ECU outlet;
- (e) a pair of coolant trunks housed in the electric vehicle,
 - (i) wherein the pair of coolant trunks includes:
 - (1) a cool trunk for receiving cooled coolant; and
 - (2) a warm trunk for discharging warmed coolant;
 - (ii) wherein the cool trunk is in fluid connection with the HE inlet of each individual energy storage device;
 - (iii) wherein the warm trunk is in fluid connection with the HE outlet of each individual energy storage device;
- (f) an internal cooling unit housed in the electric vehicle and having an ICU inlet and an ICU outlet;
- (g) a charging segmented cooling controller (SCC), the charging SCC including a set of parameters,
 - (i) wherein during each charging session the charging SCC is in direct or indirect data communication by wire or wirelessly with:
 - (1) the external cooling unit;
 - (2) the HE flow controller of each energy storage device;
 - (3) the MBMS; and
 - (4) the BMU of the segmented battery module of each energy storage device via the MBMS and the BMU connector of the energy storage device;
 - (ii) wherein during each charging session the charging SCC is configured to directly or indirectly receive the sensor information collected by the BMU of each energy storage device wirelessly or by wire via the BMU connector of the energy storage device, the sensor information including at least temperature information measured by the at least one temperature sensor located within the segmented battery module of the energy storage device;
 - (iii) wherein the set of parameters include at least a preferred temperature range for the segmented battery module of each energy storage device;
 - (iv) wherein during each charging session the charging SCC is configured to periodically:

- (1) calculate or recalculate an optimal range for the HE flow rate of the heat exchanger of each individual energy storage device, the optimal range a function of:
- (a) the sensor information received by the charging SCC from the sensors of the energy storage device via the BMU of the energy storage device; and
- (b) the preferred temperature range for the energy storage device; and
- (2) control by wire or wirelessly the HE flow rate of each individual energy storage device, via the direct or indirect data communication with the HE flow controller of the energy storage device, to maintain the HE flow rate within the optimal range; and
- (v) wherein the charging SCC is housed in the power source and, for each energy storage device, data communication between the charging SCC and the HE flow controller of the energy storage device does not pass through either:
- (1) the MBMS of the motorized electric vehicle; or
- (2) the BMU of the energy storage device
- (h) wherein during each charging session:
- (i) a segmented coolant pathway exists that provides a flow of coolant between each individual energy storage device of the motorized electric vehicle and the external cooling unit, whereby coolant is transferred between the external cooling unit and the heat exchanger of each individual energy storage device by way of the VSD coolant pump of the HE flow controller of the energy storage device, and further wherein:
- (1) for each individual energy storage device, the segmented coolant pathway includes the HE flow controller of the energy storage device, and the HE flow controller of the energy storage device has an HE flow rate therethrough; and
- (2) for each individual energy storage device, the segmented coolant pathway exits from the ECU outlet, through the cool trunk, through the HE inlet of the energy storage device, through the HE passages of the energy storage device, through the HE outlet of the energy storage device, through the warm trunk, into the ICU inlet, through the internal cooling unit, out of the ICU outlet, into the ECU inlet, and back into and through the external cooling unit; and

- (ii) the charging SCC is configured to prioritize individual cooling needs of the segmented battery modules by way of increasing or decreasing coolant flow through the HE flow controller of each individual energy storage device to establish an individualized flow of coolant to each energy storage device.

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Claim 2 The system of claim 1, wherein the charging SCC employs a control loop to:

- (a) adjust a power rating delivered to the external cooling unit;
- (b) according to the temperature information from the temperature sensor of the segmented battery module of each of the energy storage devices, prioritize delivery of coolant to at least one of the energy storage devices; and
- (c) adjust the HE flow rate of coolant through one or more of the HE flow controllers.

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Claim 6 The system of claim 1,

- (a) wherein the plurality of sensors in the segmented battery module of each energy storage device further include a current sensor configured to measure and transmit current information of the battery cells of the segmented battery module to the charging SCC via the BMU of the energy storage device;
- (b) wherein the set of parameters includes a thermal model for each energy storage device; and
- (c) wherein calculation or recalculation by the charging SCC of the optimal range for each energy storage device includes calculation or recalculation of:
 - (i) a heat generation estimate for the energy storage device from:
 - (1) the thermal model of the energy storage device;
 - (2) the current information for the energy storage device; and
 - (3) the preferred temperature range for the energy storage device; and
 - (ii) the optimal range for the HE flow rate of the energy storage device to counteract the heat generation estimate for the energy storage device.

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Claim 4 The system of claim 1,

- (a) wherein the heat exchanger and the segmented battery module of each energy storage device are paired in thermal conductivity via a thermal interface;
- (b) wherein the heat exchanger for each energy storage device includes a plurality of heat sinks conforming to outer surface areas of the segmented battery module of the energy storage device; and

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(c) wherein the thermal interface between each heat sink and the segmented battery module of each energy storage device is a compressible thermally conductive material or a thermally conductive paste.

5 Claim 5 The system of claim 4, wherein at least one heat sink of each energy storage device comprises an aluminium shell enclosing the HE passages of the energy storage device.

Claim 6 The system of claim 1,
wherein the power car includes one or more power outlets connectable to one or more power
10 inlets of the locomotive.

Claim 7 A computer-implemented method for individualized cooling of a plurality of segmented battery modules of an electric vehicle comprising one of a locomotive having at least one traction motor and a power car for the locomotive; and a power
15 source paired with and externally disposed relative to the locomotive or the power car, the method comprising:

(a) maintaining a plurality of energy storage devices in an electric vehicle, each individual energy storage device including a heat exchanger and one of the segmented battery modules in thermal conductivity with each other,

20 (i) wherein the heat exchanger of each individual energy storage device includes:

- (1) an HE flow controller comprising a variable speed drive (VSD) coolant pump for controlling flow of coolant through the heat exchanger;
- (2) an HE inlet for receiving the coolant into a plurality of HE passages within the heat exchanger; and

25 (3) an HE outlet for discharging coolant from the HE passages of the heat exchanger; and

(ii) wherein the segmented battery module of each energy storage device includes:

- (1) a plurality of battery cells in electrical connection with an electrical connection connector;
- 30 (2) a battery management module (BMU) in data communication with a plurality of sensors, the sensors including at least one temperature sensor located within the segmented battery module and the BMU configured to collect sensor information from the sensors; and
- (3) a BMU connector in wired or wireless data communication with the BMU;

- (b) maintaining an electrical connection in the electric vehicle,
 - (i) wherein the electrical connection is in electrical connection to the battery connector of each of the energy storage devices;
 - (ii) wherein the electrical connection is in electrical connection with one or more electrical connection connectors; and
 - (iii) wherein each of the one or more electrical connection connectors are connectable to one of one or more power supplies of the power source during a charging session for plurality of energy storage devices;
- (c) maintaining a master battery management system (MBMS) in the electric vehicle, wherein the MBMS is in data communication with the BMU of each energy storage device wirelessly or by wire via the BMU connector of the energy storage device; and
- (d) maintaining an external cooling unit in a power source, the external cooling unit including an ECU inlet and an ECU outlet;
- (e) maintaining a pair of coolant trunks in the electric vehicle,
 - (i) wherein the pair of coolant trunks includes:
 - (1) a cool trunk for receiving cooled coolant; and
 - (2) a warm trunk for discharging warmed coolant;
 - (ii) wherein the cool trunk is in fluid connection with the HE inlet of each individual energy storage device;
 - (iii) wherein the warm trunk is in fluid connection with the HE outlet of each individual energy storage device;
- (f) maintaining an internal cooling unit housed in the electric vehicle and having an ICU inlet and an ICU outlet;
- (g) maintaining a charging segmented cooling controller (SCC), the charging SCC including a set of parameters,
 - (i) wherein during the charging session the charging SCC is in direct or indirect data communication by wire or wirelessly with:
 - (1) the external cooling unit;
 - (2) the HE flow controller of each energy storage device;
 - (3) the MBMS; and
 - (4) the BMU of the segmented battery module of each energy storage device via the MBMS and the BMU connector of the energy storage device;
 - (ii) wherein during the charging session the charging SCC is configured to directly or indirectly receive the sensor information collected by the BMU of each energy

storage device wirelessly or by wire via the BMU connector of the energy storage device, the sensor information including at least temperature information measured by the at least one temperature sensor located within the segmented battery module of the energy storage device;

- (iii) wherein the set of parameters include at least a preferred temperature range for the segmented battery module of each energy storage device; and
- (iv) wherein the charging SCC is maintained in the power source and, for each energy storage device, data communication between the charging SCC and the HE flow controller of the energy storage device does not pass through either:

- (1) the MBMS of the motorized electric vehicle; or
- (2) the BMU of the energy storage device;

- (h) establishing for the charging session a segmented coolant pathway that provides a flow of coolant between each individual energy storage device of the motorized electric vehicle and the external cooling unit, whereby coolant is transferred between the external cooling unit and the heat exchanger of each individual energy storage device during each charging session by way of the VSD coolant pump of the HE flow controller of the energy storage device, and further wherein:

- (1) for each individual energy storage device, the segmented coolant pathway includes the HE flow controller of the energy storage device, and the HE flow controller of the energy storage device has an HE flow rate therethrough; and
- (2) for each individual energy storage device, the segmented coolant pathway exits from the ECU outlet, through the cool trunk, through the HE inlet of the energy storage device, through the HE passages of the energy storage device, through the HE outlet of the energy storage device, through the warm trunk, into the ICU inlet, through the internal cooling unit, out of the ICU outlet, into the ECU inlet, and back into and through the external cooling unit;

- (i) commencing the charging session for the plurality of energy storage devices, the step of commencing the charging session including:
 - (i) connecting the MBMS to the charging SCC; and
 - (ii) connecting the electrical connection to one or more power supplies via one or more electrical connection connectors;

(j) during the charging session, periodically employing the charging SCC to calculate or recalculate an optimal range for the HE flow rate of the heat exchanger of each individual energy storage device, the optimal range a function of:

- (i) the sensor information received by the charging SCC from the sensors of the energy storage device via the BMU of the energy storage device; and
- (ii) the preferred temperature range for the energy storage device; and

(k) during the charging session, prioritizing individual cooling needs of the segmented battery modules by way of increasing or decreasing coolant flow through the HE flow controller of each individual energy storage device under charging SCC control to establish an individualized flow of coolant to each energy storage device.

Claim 8 The method of claim 7, wherein the charging SCC employs a control loop to:

- (a) adjust a power rating delivered to the external cooling unit;
- (b) according to the temperature information from the temperature sensor of the segmented battery module of each of the energy storage devices, prioritize delivery of coolant to at least one of the energy storage devices; and
- (c) adjust the HE flow rate of coolant through one or more of the HE flow controllers.

Claim 9 The method of claim 7,

- (a) wherein the plurality of sensors in the segmented battery module of each energy storage device further include a current sensor configured to measure and transmit current information of the battery cells of the segmented battery module to the charging SCC via the BMU of the energy storage device;
- (b) wherein the set of parameters includes a thermal model for each energy storage device; and
- (c) wherein the step of periodically employing the charging SCC to calculate or recalculate the optimal range includes calculating or recalculating for each energy storage device:
 - (i) a heat generation estimate for the energy storage device from:
 - (1) the thermal model of the energy storage device;
 - (2) the current information for the energy storage device; and
 - (3) the preferred temperature range for the energy storage device; and
 - (ii) the optimal range for the HE flow rate of the energy storage device to counteract the heat generation estimate for the energy storage device.

Claim 10 The method of claim 7,

- (a) wherein the heat exchanger and the segmented battery module of each energy storage device are paired in thermal conductivity via a thermal interface;
- (b) wherein the heat exchanger for each energy storage device includes a plurality of heat sinks conforming to outer surface areas of the segmented battery module of the energy storage device; and
- (c) wherein the thermal interface between at least one heat sink and the segmented battery module of each energy storage device is a compressible thermally conductive material or a thermally conductive paste.

Claim 11 The method of claim 10, wherein the heat sink of at least one energy storage device comprises an aluminium shell enclosing the HE passages of the energy storage device.

Claim 12 The method of claim 7,

- wherein the power car includes one or more power outlets connectable to one or more power inlets of the locomotive.