METHOD AND APPARATUS FOR AN ELECTRICAL VEHICLE

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ABSTRACT

One embodiment includes a vehicle that includes a battery to supply a flow of electrical energy, an electric motor arranged to propel the vehicle, a first control circuit coupled between the battery and the motor to control the flow of electrical energy to the motor; a first heat exchange loop thermally coupled with a heat exchanger and a heating element, the first heat exchange loop to circulate a first fluid to heat or cool a passenger cabin; a second heat exchange loop thermally coupled with the heat exchanger, the second heat exchange loop to circulate a second fluid to heat or cool the battery and a second control circuit to couple a charger to the battery and to perform charging operations on the battery using a voltage source powered from a line source.
ADD INSERT(S) TO SUBSTRATE

BEND COOLING TUBE ASSEMBLY

ADD COOLING TUBE ASY ABOVE INSERT

ATTACH WALLS TO SUBSTRATE

ADD BATTERIES TO INSERT(S), ADD PC

ATTACH INSERTS OPPOSITE SUBSTRATE

ATTACH INSERT/SUBSTRATE TO BATTERIES/WALLS

CONNECT BRACKETS TO CONDUCTORS

CONNECT BRACKETS TO BATTERIES

MORE PETALS?

STOP

SELECT NEXT POSITION

FIG. 15
MOUNT MULTIPLE BATTERIES IN SUBSTRATES

SANDWICH SUBSTRATES WITH CONDUCTORS

FUSIBLY CONNECT EACH BATTERY TO EACH CONDUCTOR IN A PACK

FUSIBLY LINK CONDUCTOR OF ONE PACK TO CONDUCTOR OF ANOTHER PACK

FIG. 17

FIG. 18
CONNECT SETS OF BATTERIES IN PARALLEL

COUPLE SETS IN SERIES TO MAKE A PACK

STACK MULTIPLE PACKS ADJ TO ONE ANOTHER

EXTEND TERMINALS TO EDGE OF PACK

CONNECT TERMINALS VIA FLEXIBLE BUS BAR

COUPLE TO POWER SOURCE OF VEHICLE

FIG. 20

FIG. 24
MOUNT MULTIPLE BATTERIES IN SUBSTRATE

RUN TUBE(S) ADJACENT TO EACH BATTERY

PLACE THERMALLY-CONDUCTIVE MATERIAL AROUND BATTERIES AND OPTIONALLY TUBES

BATTERY RELEASES EXCESSIVE HEAT

HEAT DISTRIBUTED TO THERMALLY CONDUCTIVE MATERIAL

HEAT DISTRIBUTED TO MULTIPLE BATTERIES

FIG. 26

FIG. 27
STACK LAMINATED STEEL PLATES

ADD COPPER BARS BETWEEN TEETH

ADD SLUGS ABOVE/BETWEEN TEETH AND BETWEEN BARS

AXIALLY CLAMP OR SPRING CLAMP SLUGS TO TEETH

RADIALY SPRING COMpress SLUGS TO ENDS OF BARS

HEAT TO BRAISE SLUGS TO BARS

COOL USING ANNEALING SCHEDULE

REMOVE CLAMPS, BOLTS, PLATES, SPRINGS, SHAPE

HEAT BERILLIUM COPPER BAND

SLIP BAND OVER EDGES TO MID PART OF SLUGS

ALLOW ASSEMBLY TO REACH ROOM TEMP

COMPLETE ROTOR, BUILD MOTOR

BUILD PRODUCT: CAR, ROCKET, ETC.

FIG. 28

FIG. 29B
PERIODICALLY SAMPLE VOLTAGES OF ALL LOCAL BRICKS

COMPUTER LOCAL TARGET BALANCE VOLTAGE

TIMEOUT OR INITIALIZE BALANCE VOLTAGE?

SET TARGET BALANCE VOLTAGE TO LOCAL TARGET BALANCE VOLTAGE

ANNOUNCE LOCAL TARGET BALANCE VOLTAGE

RECEIVE ANNOUNCED LOCAL TARGET BALANCE VOLTAGE FROM OTHER BMBS

SET TARGET BALANCE VOLTAGE TO ANNOUNCED LOCAL TARGET BALANCE VOLTAGE IF APPROPRIATE

COMPARE TARGET BALANCE VOLTAGE WITH LOCAL BRICK VOLTAGES. ADJUST LOCAL BRICK VOLTAGES IF OUTSIDE OF TARGET BALANCE VOLTAGE DELTA AND LOCAL BRICK VOLTAGES ARE WITHIN SAFETY LIMITS

FIG. 46
CHECK IF WEAK SHORT EXISTS

CHECK FOR A WEAK SHORT?

YES

RUN WEAK SHORT SEARCH ALGORITHM

BAD CELL IDENTIFICATION?

NO

YES

TURN OFF SWITCH TO CELL

FIG. 53

FIG. 54

FIG. 55
FIG. 90

USER INTERFACE
Mobile device or other communication device such as email or IM, etc.

CDMA
OTHER
TDMA
GSM

NETWORK (ex: cell tower, computer network, satellite)

TCP/IP
GPRS
OTHER
OTHER

VEHICLE
with 802.11 and/or cellular phone chip (ex: CircumNav chip)

NETWORK (ex: Tesla server or Utility company server)

DATA STORAGE (CYCLE COUNT, TEMP, ETC.)

DATA ANALYSIS

USER
FIG. 94
FIG. 95A

FIG. 95B
DETERMINING THAT A CHARGE OPERATION IS TO BE PERFORMED ON A RECHARGEABLE BATTERY PACK

COMPARING A SUPPLY VOLTAGE TO A TERMINAL VOLTAGE OF THE RECHARGEABLE BATTERY PACK TO DETERMINE A LINE VOLTAGE OFFSET VALUE

GENERATING A CHARGING VOLTAGE FROM THE SUPPLY VOLTAGE

INITIATING CHARGING OF THE RECHARGEABLE BATTERY PACK BY COUPLING THE CHARGING VOLTAGE TO THE RECHARGEABLE BATTERY PACK

COUPLING A HEATING ELEMENT IN THE CHARGING CIRCUIT

COMPARING THE SUPPLY VOLTAGE TO THE TERMINAL VOLTAGE OF THE BATTERY PACK WHILE CHARGING THE RECHARGEABLE BATTERY PACK AND HAVING THE HEATING ELEMENT IN THE CHARGING CIRCUIT

BYPASSING THE HEATING ELEMENT

CIRCULATING THE FLUID THROUGH THE RECHARGEABLE BATTERY PACK DURING THE CHARGING

TERMINATING THE CHARGING OF THE RECHARGEABLE BATTERY PACK WHEN VOLTAGE OF THE BATTERY PACK REACHES A PRE-DETERMINED VOLTAGE CHARGE LEVEL

FIG. 96
DISPOSING A BOTTOM PORTION OF A FIRST BATTERY INTO A FIRST BOTTOM RECESS OF A BOTTOM CLAMSHELL

DISPOSING A BOTTOM PORTION OF A SECOND BATTERY INTO A SECOND BOTTOM RECESS OF THE BOTTOM CLAMSHELL


FIG. 104
FIG. 106

ELECTRICAL VEHICLE CHARGING SYSTEM

200S

202S

204S

206S

208S

210S

212S

FIG. 106

ELECTRICAL VEHICLE

CHARGING CIRCUIT

BATTERY

CHARGING CIRCUIT

TIMER

FIG. 107

MEMORY

INFORMATION

PROCESOR(S)
Determing Charging Cost Rate

Charging a battery of an electric vehicle to a first energy stored level while a first charging cost rate is determined.

Charge to a second energy stored level?

Yes: Charging to a second energy stored level while a second charging cost rate is determined, wherein the second energy stored level is higher than the first energy stored level.

No: END

FIG. 108
STORING A USER SELECTED DRIVING RANGE FOR AN ELECTRIC VEHICLE

DETERMINING A POTENTIAL DRIVING RANGE BASED ON A PATTERN OF DRIVING RANGES ACHIEVED BY CHARGING A BATTERY OF THE ELECTRIC VEHICLE TO A FIRST PERCENTAGE OF CAPACITY

DETERMINING WHETHER A FIRST AMOUNT OF ENERGY STORED WHEN THE BATTERY IS CHARGED TO THE FIRST PERCENTAGE OF CAPACITY IS SUFFICIENT TO ACHIEVE THE USER SELECTED DRIVING RANGE BASED ON THE PATTERN OF DRIVING RANGES ACHIEVED

CHARGING THE BATTERY TO THE FIRST PERCENTAGE OF CAPACITY IF THE FIRST AMOUNT ENERGY STORED IS SUFFICIENT TO POWER THE ELECTRIC VEHICLE THROUGH THE SELECTED DRIVING RANGE

CHARGING THE BATTERY TO A SECOND PERCENTAGE OF CAPACITY, WHICH IS HIGHER THAN THE FIRST PERCENTAGE OF CAPACITY, IF THE FIRST ENERGY STORED IS NOT SUFFICIENT TO POWER THE ELECTRIC VEHICLE THROUGH THE USER SELECTED DRIVING RANGE

FIG. 113
CONNECTING A CHARGING COUPLER TO A CHARGING COUPLER PORT OF AN ELECTRIC VEHICLE

COMMUNICATING A CHARGER CONNECTION SIGNAL INDICATIVE OF THE STATE OF CONNECTION OF THE CHARGING COUPLER AND THE CHARGING COUPLER PORT TO A LIGHTING CONTROLLER

DETERMINING A CHARGE STATE SIGNAL INDICATIVE OF THE CHARGE STATE OF A BATTERY COUPLED TO THE ELECTRIC VEHICLE

COMMUNICATING THE CHARGE STATE SIGNAL TO THE ILLUMINATED INDICATOR CONTROLLER

PROVIDING AN EXTERNAL INDICATION OF THE CHARGER CONNECTION SIGNAL AND THE CHARGE STATE SIGNAL BY CONTROLLING THE BRIGHTNESS AND THE COLOR OF ILLUMINATED INDICATOR COUPLED TO THE CHARGING COUPLER PORT

FIG. 120
FIG. 122

Cooling Subsystem

Control

Battery Circulation

Cabin Circulation

FIG. 123

Cooling Subsystem

Zone 1

Valve

Battery Zone

Processor

Control

Temp
Estimate Time Before Battery Depletion

Monitor Battery Temperature

Request Cooling

Estimating Time Before Battery Temp Reaches Threshold

Request Cooling

FIG. 124

FIG. 125
METHOD AND APPARATUS FOR AN ELECTRICAL VEHICLE

[0001] This application claims the benefit of priority under 35 U.S.C. 119(e) to U.S. Provisional Patent Application Ser. No. 60/950,600, filed on Jul. 18, 2007, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Electric vehicles generally include vehicles that have some device, usually a battery, that stores energy, and that is operable to provide electrical power to one or more systems used, to at least in part, propel or to accelerate the electrical vehicle, or to provide the energy required for some motions of the vehicle. As the stored energy is consumed through either use in the electric vehicle or through some other form of energy dissipation, the source of the stored energy needs to be re-charged in order to replenish the level of stored energy.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. 1 is a block diagram of a bank of batteries according to one embodiment of the present invention.
[0004] FIG. 2A is a diagram showing a creation of a mount and a hole in the substrate used to hold the batteries in the bank according to one embodiment of the present invention.
[0005] FIG. 2B is a diagram of four mounts in a substrate used to hold batteries in a bank according to one embodiment of the present invention.
[0006] FIG. 3 is a side view of a bank of batteries including two substrates and two conductors with electrical connection brackets according to one embodiment of the present invention.
[0007] FIG. 4 is a diagram of two conductors with a representative bracket, including an alternate view of the bracket to show its geometry according to one embodiment of the present invention.
[0008] FIG. 5 is a side view of five sets of batteries coupled using conductors according to one embodiment of the present invention.
[0009] FIG. 6A is a block diagram of the end conductors from two different stacks of multiple sets of batteries and a connector between the stacks according to one embodiment of the present invention.
[0010] FIG. 6B is a diagram of a single connector expansion piece according to one embodiment of the present invention.
[0011] FIG. 6C is a diagram of a ledge of the connector expansion piece of FIG. 6B showing a nut inserted therein, and a bolt screwed into the nut according to one embodiment of the present invention.
[0012] FIG. 7 is a diagram of an expandable connector, including two of the expansion pieces of FIG. 6B according to one embodiment of the present invention.
[0013] FIG. 8A is a block diagram of an overhead view of one or more sets of batteries showing the direction of an upper and lower cooling tube cooled via a heat exchanger coupled to an air conditioner according to one embodiment of the present invention.
[0014] FIG. 8B is a block diagram of an overhead view of one or more sets of batteries showing the direction of an upper and lower cooling tube cooled via a heat exchanger coupled to an air conditioner according to one embodiment of the present invention.
[0015] FIG. 8C is a cross sectional view of a structure that contains a pair of tubes according to one embodiment of the present invention.
[0016] FIG. 9 is a block diagram of the side view of a row of the sets of batteries illustrating the upper and lower tubes from a different perspective than can be shown in FIG. 8A, according to one embodiment of the present invention.
[0017] FIG. 10A is a diagram of a portion of an insert including mounts with integrated air holes according to one embodiment of the present invention.
[0018] FIG. 10B is a diagram of a mount being drilled according to one embodiment of the present invention.
[0019] FIG. 10C is a diagram of the reverse side of a portion of a mount behind a mount according to one embodiment of the present invention.
[0020] FIG. 10D is a diagram of three mounts shown from the side, including a key under the insert according to one embodiment of the present invention.
[0021] FIG. 10E is a diagram of two air cooled battery assemblies according to one embodiment of the present invention.
[0022] FIG. 10F is a diagram of three air cooled battery assemblies according to one embodiment of the present invention.
[0023] FIG. 11 is a diagram of a substrate and walls according to one embodiment of the present invention.
[0024] FIG. 12A is a diagram of a substrate, inserts, a cooling tube assembly and walls according to one embodiment of the present invention.
[0025] FIG. 12B is an exploded view of a battery assembly, partially filled with two of the dozens of batteries it may contain according to one embodiment of the present invention.
[0026] FIG. 13 is a flowchart illustrating a method of assembling substrates, inserts, cooling tubes, walls, batteries, and conductors according to one embodiment of the present invention.
[0027] FIG. 14 is a flowchart illustrating a method of mounting batteries in a battery assembly according to one embodiment of the present invention.
[0028] FIG. 15 is a flowchart illustrating a method of mounting batteries according to one embodiment of the present invention.
[0029] FIG. 16A is a side view of a portion of a battery pack according to one embodiment of the present invention.
[0030] FIG. 16B is a top view of the battery pack of FIG. 16A according to one embodiment of the present invention.
[0031] FIG. 17 is a block schematic diagram of a set of two battery packs and a fuse according to one embodiment of the present invention.
[0032] FIG. 18 is a flowchart illustrating a method of fusibly coupling batteries according to one embodiment of the present invention.
[0033] FIG. 19 is a block schematic diagram of a system of parallel-interconnected battery packs according to one embodiment of the present invention.
[0034] FIG. 20 is a flowchart illustrating a method of connecting battery packs according to one embodiment of the present invention.
FIG. 21 is a block-schematic diagram of a system of series-interconnected battery packs according to another embodiment of the present invention.

Fig. 22A and 22B are a diagram of the conductors of each of the two sides of a battery pack according to one embodiment of the present invention.

Fig. 23C and 22D are a diagram of the conductors of each of the two sides of a battery pack according to another embodiment of the present invention.

FIG. 23 is a block-schematic diagram of a system of series- and parallel-interconnected battery packs according to another embodiment of the present invention.

FIG. 24 is a block schematic diagram of a vehicle containing the set of interconnected battery packs of FIG. 19, 21, 23, or any of these according to one embodiment of the present invention.

FIG. 25A is a diagram of a system of battery cells inhibited from thermal chain reactions according to one embodiment of the present invention.

FIG. 25B is a side view of two of the rows of battery cells in the system of FIG. 25A according to one embodiment of the present invention.

FIG. 25C is a side view of battery cells at least partly surrounded by a thermally-conductive sheet according to one embodiment of the present invention.

FIG. 25D is an overhead view of battery cells at least partly surrounded by a thermally-conductive sheet according to one embodiment of the present invention.

FIG. 26 is a flowchart illustrating a method of manufacturing a chain-reaction-inhibiting battery cell pack and distributing heat generated from one battery cell to several battery cells according to one embodiment of the present invention.

FIG. 27 is a diagram of a conventional vehicle with the battery cell assembly of the present invention.

FIG. 28 is a flowchart illustrating a method of assembling an electric motor rotor according to one embodiment of the present invention.

FIG. 29A is an expanded view of the electric motor rotor according to one embodiment of the present invention.

FIG. 29B is a view of the discs, bars, and slugs of the rotor of FIG. 29A wrapped with wires according to another embodiment of the present invention.

FIG. 30 is a cross sectional view of one of the discs in the stack of discs shown in FIGS. 29 and 31 according to one embodiment of the present invention.

FIG. 31 is an exploded view of the electric motor rotor of FIG. 29 according to one embodiment of the present invention.

FIG. 32 is a schematic illustration of a thermal management system in accordance with the invention.

FIG. 33 is a schematic illustration of the primary components of the rotor assembly cooling system;

FIG. 34 is a cross-sectional view of one embodiment of a feed tube support member utilizing a plurality of support spokes;

FIG. 35 is a cross-sectional view of an alternate embodiment of a feed tube support member utilizing a plurality of support spokes coupled to a pair of concentric mounting rings.

FIG. 36 is a cross-sectional view of a perforated feed tube support member;

FIG. 37 is a cross-sectional view of a slotted feed tube support member;

FIG. 38 is an illustration of an alternate rotor assembly cooling system using a helical support strut between the coolant feed tube and the bore of the rotor drive shaft;

FIG. 39 is an illustration of an alternate rotor assembly cooling system using an internally shaped drive shaft; and

FIG. 40 is a conceptual illustration of the rotor assembly cooling system within an electric motor system.

FIG. 41 shows battery cells connected in parallel to form a brick according to the present invention.

FIG. 42 shows bricks of battery cells connected in series to form a sheet according to the present invention.

FIG. 43 shows an architectural representation of an energy storage system (ESS) according to the present invention.

FIG. 44 shows a top view of a battery monitoring board (BMB) according to the present invention.

FIG. 45 shows a perspective view of a battery monitoring board (BMB) according to the present invention.

FIG. 46 shows a flow chart of a methodology of balancing batteries according to the present invention.

FIG. 47 is a schematic view of an electric vehicle communication interface and associated methodology according to the present invention.

FIG. 48 is a flow chart showing the electric vehicle communication interface according to the present invention.

FIG. 49 shows a top view of a battery pack system according to the present invention.

FIG. 50 shows a top view of one battery cell connected to a collector plate via a conductor according to the present invention.

FIG. 51 shows a partial cross sectional view of a battery pack system according to the present invention.

FIG. 52 shows a top view of a battery cell according to the present invention.

FIG. 53 shows a side view of an apparatus for deactivating bad battery cells according to the present invention.

FIG. 54 shows a top view of an apparatus for deactivating bad battery cells according to the present invention.

FIG. 55 shows a flow chart of one methodology of deactivating faulty or bad battery cells according to the present invention.

FIG. 56 shows a view of a sheet which is a subsystem of an energy storage system (ESS) according to the present invention.

FIG. 57 shows a view of an energy storage system enclosure according to the present invention.

FIG. 58 shows thermistors attached to six different cells of the energy storage system according to the present invention.

FIG. 59 shows a view of a manifold according to the present invention.

FIG. 60 shows a side view of a cooling tube according to the present invention.

FIG. 61 shows an end view of a cooling tube arranged within a tube seal plug according to the present invention.

FIG. 62 shows a side view of a cooling tube according to the present invention.

FIG. 63 shows a top view of a cooling tube interengaged with cells of a sheet of an energy storage system according to the present invention.

FIG. 64 shows a view of the end fittings arranged over an end of a cooling tube according to the present invention.
FIG. 65 shows the connection of a manifold and tube seal plug to an ESS enclosure according to the present invention.

FIG. 66 shows the counter flow architecture of the thermal management system according to the present invention.

FIG. 67 shows an energy storage system according to the present invention.

FIG. 68 shows a battery module or sheet having an electrical pyrometer therein according to the present invention.

FIG. 69 shows a view of a battery module in infrared showing the infrared photons from one hot cell reflecting throughout the module.

FIG. 70 shows a radiation energy density diagram within a battery module for normal and hot cell conditions.

FIG. 71 shows a battery module according to the present invention having an optical pyrometer arranged therein and at least one reflective surface arranged therein.

FIG. 72 shows a manifold connected to an energy storage system (ESS) enclosure according to the present invention.

FIG. 73 shows an energy storage system according to the present invention.

FIGS. 74 A and B shows a top view of a cooling tube having an optimized geometry according to the present invention.

FIG. 75 A-D shows a perspective view, a top view, an end view and a side view of a scalloped cooling tube for use in a thermal management system according to the present invention.

FIG. 76 shows a perspective view of a scalloped cooling tube according to the present invention.

FIG. 77 shows a close up view of a scalloped cooling tube according to the present invention.

FIG. 78 shows a scalloped cooling tube arranged between adjacent rows of cells according to the present invention.

FIG. 79 shows a compressible thermal pad for use with a cooling tube according to the present invention.

FIG. 80 shows a die used to create a scalloped cooling tube according to the present invention.

FIG. 81 shows an alternate embodiment of a die used to make a scalloped cooling tube according to the present invention.

FIG. 82 shows a thermally conductive compound used to fill space between the cells in a battery pack.

FIG. 83 shows an aluminum cooling tube potted in with the cells of a battery pack.

FIG. 84 A-B show metal collector plates arranged on each end of the cells of a battery pack.

FIG. 85 shows the cells arranged in an array in space.

FIG. 86 shows normal operating cells oriented transversely relative to a hot cell in the middle.

FIG. 87 shows normal cells oriented axially relative to a hot cell in the middle.

FIG. 88 shows an insulator arranged around each end of a plurality of cells of a battery pack.

FIG. 89 shows a diagram of a system for mitigation of propagation of a thermal runaway event within an energy storage system according to the present invention.

FIG. 90 is a schematic view of an electric vehicle communication interface and associated methodology according to the present invention.

FIG. 91 is a flow chart showing the electric vehicle communication interface according to the present invention.

FIG. 92 shows a vehicle system to various embodiments of the present subject matter;

FIG. 93A shows a functional block diagram of a charging system 200Q for a battery pack 252Q according to various embodiments of the present subject matter;

FIG. 93B shows a charging circuit according to various embodiments of the present subject matter;

FIG. 93C shows a charging circuit according to various embodiments of the present subject matter;

FIG. 94 shows a charging station according to various embodiments of the present subject matter;

FIG. 95A shows a graph including a voltage waveform according to various embodiments of the present subject matter;

FIG. 95B shows a graph 450Q of a voltage level for a battery pack during a charging operation according to various embodiments of the present subject matter;

FIG. 96 shows a flowchart for one or more methods according to various embodiments of the present subject matter.

FIG. 97A shows diagrams of voltage levels according to various embodiments of the present subject matter;

FIG. 97B shows diagrams of voltage levels according to various embodiments of the present subject matter.

FIG. 98 is a high level diagram of an electric vehicle, according to one embodiment.

FIG. 99 is a partial perspective view of a clamshell, according to one embodiment.

FIG. 100 is a cross section taken along line 3-3 in FIG. 2.

FIG. 101 is a cross section taken along line 4-4 in FIG. 2.

FIG. 102 is a partial perspective view of a clamshell including a protrusion, according to one embodiment.

FIG. 103 is a cross section taken along line 6-6, according to one embodiment.

FIG. 104 is a process according to one embodiment.

FIG. 105 is a high level diagram of an electric vehicle, according to one embodiment.

FIG. 106 is a diagram of an electrical vehicle charging system, according to one embodiment.

FIG. 107 is a block diagram of an article according to various embodiments of the invention.

FIG. 108 is a method of charging a battery, according to one embodiment of the present subject matter.

FIG. 109 is a method of charging a battery to a first energy stored level during a first time period and charging the battery during a second time period, according to one embodiment of the present subject matter.

FIG. 110 is a method of charging a battery during a second time period, according to one embodiment of the present subject matter.

FIG. 111 is a method of charging to a first energy stored level during a first time period, and to a second energy stored level during a second time period, according to one embodiment of the present subject matter.
FIG. 112 is a method of charging a battery in the context of a charging rate that varies up and down throughout the day, according to one embodiment of the present subject matter.

FIG. 113 is a method according to one embodiment of the present subject matter.

FIG. 114 is a method of charging a battery to achieve a selected range, according to one embodiment of the present subject matter.

FIG. 115 is a high level diagram of an electric vehicle with a battery and a charging indicator, according to one embodiment of the present subject matter.

FIG. 116 shows a vehicle system, according to one embodiment of the present subject matter.

FIG. 117 illustrates a partial perspective view of a system including an electric vehicle, a charger, a charging coupler port, and other components, according to one embodiment.

FIG. 118 illustrates a cross section along line 4-4 in FIG. 117.

FIG. 119 illustrates a perspective view of a charging coupler port, according to one embodiment.

FIG. 120 illustrates a process for indicating charge, according to one embodiment.

FIG. 121 shows a vehicle system according to one embodiment of the present subject matter.

FIG. 122 is a block diagram of a system for cooling a battery and cabin according to various embodiments.

FIG. 123 is a block diagram of a system for cooling multiple zones according to various embodiments.

FIG. 124 is a flow diagram illustrating a method for cooling a battery according to various embodiments.

FIG. 125 is a flow diagram illustrating another method for cooling a battery according to various embodiments.

FIG. 126 is a block diagram of an example system according to some embodiments.

DETAILED DESCRIPTION

In the following description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present invention. The following description of example embodiments is, therefore, not to be taken in a limited sense, and the scope of the present invention is defined by the appended claims.

Referring now to FIG. 1, a substrate used to hold one or more sets of one or more batteries is shown according to one embodiment of the present invention. The batteries used in one embodiment are any conventional rechargeable batteries having an 18650 form factor, but other types of batteries and other form factors may be used.

The substrate 112 may be made of a material that electrically insulates one face of the substrate from the other face. The substrate 112 has at least two faces and may or may not be substantially flat. In one embodiment, the substrate 112 has two primary faces, both of which are made of an electrically insulating material. In one embodiment, the substrate is a single layer of such insulating material, such as fiberglass or plastic, and in another embodiment, one or more layers of a conducting material are formed in the substrate in the manner of a conventional printed circuit board to allow wiring for sensors to be run along as part of the substrate.

The substrate 112 may be cut or formed into a shape that matches or somewhat matches two of the dimensions of a space available for batteries. As shown in the figure, the substrate 112 has an irregular shape, but regular shapes (e.g., a triangle or square) may also be used. This can allow a higher number of batteries to occupy the space available for such batteries than would be possible if the substrate 112 shape did not match the space available. Although the shape of the substrate 112 can help to maximize the number of batteries that can fit into a space, as noted below, in one embodiment, the batteries are not so tightly packed as to have the sides of each battery touching another, but instead are spaced from one another to allow for cooling and to allow for dimensional tolerance of the batteries. In one embodiment, the batteries are spaced to allow for cooling of the batteries, either by air cooling or cooling via tubes running between the batteries as described in more detail below.

In one embodiment, the substrate 112 has a substantially flat shape. In one embodiment, the substrate 112 is a 3/8 inch thick fiberglass sheet, however, as described below, injection-molded plastic may be used, as well as other substrates. Any electrically-insulating material may be used for a substrate 112.

In one embodiment, the substrate is substantially rigid, to allow it to distribute force applied to one portion of the substrate among a wider area. As noted below, batteries are sandwiched between two substrates, and if the substrate is rigid, a force applied perpendicularly to the surface of the substrate 112 external to that of the batteries, will be distributed by the substrate 112 across two or three or four or five or more of the batteries and potentially many more. As noted below, the force may also be applied to spacers, walls or other structured components of the finished assembly. Thus, each of the batteries will be required to withstand only a fraction of the force, making it less likely that the force will crush any battery. In one embodiment, dozens of batteries and spacers and/or walls are sandwiched between a substrate that is sufficiently thick to distribute a force across many of the batteries, making it extremely resistant to crushing. As described below, spacers, walls, or both may be sandwiched between the substrate in addition to the batteries, either near the sides of the substrate or interior thereto or both, and if the spacers or walls have a crushing strength greater than the batteries, the spacers and/or walls add additional crush strength to the sandwich of batteries and substrate.

In one embodiment, each substrate 112 has a mount 110 for the insertion of each battery held by the substrate. In one embodiment, there are multiple mounts on the substrate, allowing a substrate to hold multiple batteries. The mount 110 may be raised from the substrate 112 or retracted into it or both. Batteries are inserted into mounts 110, which are milled, molded or otherwise formed in the substrate 112 or, as noted below, the mounts may be milled, molded or otherwise formed into an insert to the substrate 112.

In one embodiment, mount 110 is a well, and such embodiment will now be described, although the description of how the well is used is applicable to any form of mount 110. In one embodiment, the well extents from one surface of the substrate, part way into the substrate 112. For example, for a 3/8 inch substrate, the well may be 1/4 inch deep. The well may
be shaped so that it holds the end of the battery when a battery is pressed into it. In one embodiment, a well is formed as will now be described with reference to FIG. 2A, which shows the various positions of a milling tool used to mill each well in the substrate.

[0158] Each well 200 will hold one of the two ends of each battery to be mounted in the substrate. Referring now to FIG. 2A, a well 200 is shown according to one embodiment of the present invention. In one embodiment, a well 200 is milled using an 1/16 inch mill bit. The end of the bit is brought into contact with the surface of the substrate 112 to drill a pilot hole 210 part way through the substrate, for example 3/4 inch deep in a substrate that is thicker than 1/4 of an inch. The bit is then moved sideways 1/2,000 of an inch from the pilot hole in three or more directions, so as to form “petals” extending from the pilot hole 210. As shown in the figure, four directions are used to make four petals, with the bit being brought to position 212, then to position 214, then back to the position of the pilot hole 210, and, from the position of the pilot hole, to position 216 and then to position 218. The bit is moved 1/2,000 of an inch from the pilot hole center for each of the four directions. The resulting hole is slightly smaller than the battery at several points 222, 224, 226, 228, such points being referred to as “teeth”. Teeth 222, 224, 226, 228 are thin (e.g. they have about the same or a smaller cross section than the thickness of the substrate that comes in contact with the battery when mounted) or narrow areas of substrate 112 that contact the battery inserted in the mount and hold it at modest to high force per square inch as compared with the other edges of the well 200, which may not contact the battery at all. The force may be at least large enough so that a battery will not wobble or fall over when inserted into the mount. The teeth 222, 224, 226, 228 may slightly deform when a battery is inserted into the well, allowing the teeth 222, 224, 226, 228 to hold the battery in place when the battery is inserted.

[0159] A hole 230 is then drilled from either direction all the way through the substrate 112. In one embodiment, hole 230 is centered at the pilot hole of the well 200, and has a diameter approximately equal to, or slightly smaller than, the diameter of the positive button terminal of the battery. In this arrangement, substrate 212 will protect the negative body of the battery from being shorted to the positive terminal in the event that a conductor in contact with the positive terminal of the battery near the face of the substrate 112 outside of the face holding the battery is pushed towards the batteries. The hole 230 will allow electrical connection to the terminals of the battery as described in more detail below. Hole 230 is not considered part of the well 200 or other mount in one embodiment, and in another embodiment, it is.

[0160] There are other ways of providing a mount 110 and hole 230 for each end of each battery held by substrate 112. Referring now to FIG. 2B an alternate manner of providing a mount 110 and a hole in substrate 112 is shown. In this embodiment, substrate 112 may be molded from conventional plastic, such as by using conventional injection molding techniques. Substrate 112 is shown with four wells 240 used to hold the ends of each of four batteries (not shown). Although four wells 240 are shown in one embodiment, there may be any number of wells 240. The wells 240 are areas of the substrate 112 that are thinner than other areas of the substrate 112, for example, if the substrate between the wells is generally 1/2" thick plastic, the wells may be formed so that the thickness of the plastic is 1/8" within the well. The side of the substrate 112 opposite the well 240 may be completely flush with the remainder of the substrate. The well 240 forms a depression in the substrate 112 to admit one end of the battery. Each well may have a substantially circular shape, though other shapes may be used. Each well 240 has several fins 244 to hold the battery, the fins 244 having a relatively narrow thickness, such that they can deform when a battery is inserted into the well and operate like the teeth described above. The circular area 246 exposed by the fins 244 is slightly less than the cross section of the end of the battery being inserted, and in one embodiment, the areas 246 may be slightly smaller or larger based on the polarity of the battery end being inserted. A hole 242 is formed or drilled in the substrate 112 to allow electrical connection to the batteries, and serves the same purpose and has the same geometry relative to the well 240 as hole 230 had relative to well 200.

[0161] The holes are shown herein as being round, but holes may have any shape. Holes and the elements that hold the batteries may be any shape.

[0162] Referring now to FIG. 3, a cross section of a substrate 112 of FIG. 1, and another substrate 320 sandwiching batteries 310, 312 is shown according to one embodiment of the present invention. In one embodiment, substrate 320 is a mirror image of substrate 112 described above, and otherwise is of similar or identical manufacture as substrate 112.

[0163] Batteries 310, 312 are inserted into one substrate 320, and then a press may be used to press the opposite substrate 112 onto the other end of the batteries. As noted below, spacers such as spacer 364 may be inserted into spacer wells 360 in substrate 320 before substrate 112 is pressed onto batteries 310, 312 to allow spacer 364 to be a part of the structure containing batteries 310, 312, spacers 364 and substrate 112, 320. Spacer 364 provides added crush strength to the structure formed by the batteries 310, 312 and the substrates 112, 320, and the screws or other fasteners (not shown) that may connect the substrates 112, 320 to the spacer 364 via hole 362 (and the opposite hole in substrate 112) provide a clamping force to hold the substrates 112, 320 more securely against the batteries 310, 312.

[0164] Although only two batteries are shown in the Figure, any number of batteries may be employed in a similar fashion. Although only one spacer 364 is shown, any number may be used at the periphery of the substrates 112, 320, interior thereto, or any of these locations.

[0165] Hole 230 and similar hole 344 in the substrates 112, 320 permit electrical connection to battery 310, and other similar holes on either end of other batteries, permit electrical connection between the terminals 314, 316 of the batteries 310, 312 and two different conductors 340, 350. In one embodiment, conductors 340, 350 are made of a conducting material such as copper or copper plated metal and have the shape of plates. In one embodiment, the plates are rigid, having a thickness in excess of approximately 20,000 of an inch. In each conductor 340, 350 are holes 346, 356 placed so that the holes 346, 356 will be approximately at the location of the battery terminals 314, 316 when the conductors 340, 350 are mounted to the substrates 112, 320. The conductors 340, 350 may be mounted using spacers to hold the conductors 340, 350 slightly off of the substrates 112, 320, just outside of the area in which the battery is sandwiched, or the conductors 340, 350 may be attached directly to, on the face outside of, their respective substrates 112, 320. Conductors 340, 350 may be glued to the substrates or may be held down by the welds to the batteries as described below. In one
embodiment, conductors 340, 350 are a part of the substrates 112, 320 themselves, in the manner of a printed circuit board.

[0166] In one embodiment, the conductors 340, 350 have attached thereto, brackets 342, 352 made of a conducting material, such as tin, nickel or copper. In one embodiment, there is one bracket 342, 352 attached to the conductor 340, 350 per battery 310, 312 that is or will be electrically connected to the conductor 340, 350, although other embodiments employ multiple brackets as a single strip. In one embodiment, before attaching the conductors to the batteries 310, 312, the bracket 342, 352 is inserted into a hole 346, 356 in the conductor 340, 350. In one embodiment, in each conductor 340, 350, there is one hole 346, 356 and one bracket 342, 352 per battery that a conductor 340, 350 will contact. When all of the brackets 342 of a conductor 340 have been inserted into the holes of that conductor 340, the brackets are then wave soldered, welded, infrared reflow soldered or otherwise electrically connected to the conductor 340, thereby forming an electrical connection between the brackets 340 and the conductor 342. Other methods of electrically connecting the brackets 342 of a conductor 340 and the conductor 340 may be employed. In one embodiment, the holes 346, 356 in the conductors 340, 350 are on the same centers as, but smaller than, the holes 230, 344 in substrates 112, 320.

[0167] A representative bracket 342 and conductor 340 are shown from a different angle in FIG. 4. As can be seen in FIGS. 3 and 4, brackets, such as bracket 342 have a substantially U shape with the ends bent outward so that they can be inserted into the holes such as hole 346, one bracket per hole. Each bracket may be made of a shape, material or both to allow it to have at least a slight give, to allow the brackets 342 to compensate for variation in battery placement within the mounts and the substrate and optionally, the inserts used to mount the batteries as described herein. In one embodiment, each bracket, or multiple portions of a strip, has a shape substantially as shown in the expanded view of FIG. 4 that allows for a spring action to accommodate variations in lengths of the batteries and tolerances in substrates, mounts, and the like. Bends forming the surfaces 420 provide the spring action, with the distance between the underside of the topmost horizontal stripe and the underside of the bottommost horizontal surface at least as large as the maximum expected distance between the outside of the conductor 340 and the edge of the any terminal of any of the batteries. Stiffeners 422 are a bent piece of the bracket 342 that helps keep the lowermost horizontal surface substantially flat. The geometry and dimensions of the bracket 342 may be arranged to ensure that if it is crushed into the positive terminal, it does not spay into the negative case of the battery, but instead, side surfaces compress inwards.

[0168] Although only one bracket is shown in the Figure, each hole shown may have a bracket inserted in the same manner as is shown and wave soldered to each conductor 340, 412 in one embodiment. In one embodiment, a single bracket 348 in the shape of multiple end-to-end brackets 342 spans multiple holes, to reduce the manufacturing costs of installing multiple brackets.

[0169] The holes such as hole 346 are positioned to have the same spacing as the batteries 310, 312 over which they will be positioned so that when a conductor such as conductor 340 is placed into position above or below a set of batteries, that each of the brackets for that conductor will contact a terminal 314 or 316 of a different one of the batteries in the set or sets of batteries to which the conductor 340 is in physical and electrical contact.

[0170] The conductors 340, 350 may be mounted to the substrate 112 or 320 so that each of at least one of the brackets 342, 352 are in contact with at least one terminal 314 or 316 of a battery 310, 312 mounted or to be mounted in substrate 112 and 320. In one embodiment, the distance d of bracket 342 is such that it will extend through the hole 346 in the conductor 340 and the hole in the substrate 320 and any space between the conductor 340 and the substrate 320 and contact a battery 310, 312, even if the battery 310, 312 is not fully seated into its mount. Bracket 352 is similarly or identically sized for its conductor 350, substrate 112 and any spacing between the two.

[0171] In one embodiment, each bracket 342, 352 may then be physically attached, such as via a weld from a spot welder or laser, to the terminal 314, 316 to which it is connected.

[0172] Spacer well 360 admits a metal or plastic spacer 364 with optional holes drilled into both ends of (and optionally, all the way through) the spacer 364 to admit a screw (not shown) to be inserted into hole 362 from under substrate 320 and screwed into the spacer 364. Another screw may be screwed into the other end of spacer 364 from above substrate 112. Spacers may be positioned along the periphery of the substrates 320, 112 or interior thereto or both types of positions of spacers may be used.

[0173] In one embodiment, the batteries 310, 312 are arranged in sets of one or more batteries 310, 312, with all of the batteries in the same set being oriented with the same polarity in one direction, and all of the batteries in the same having their terminals 314, 316 electrically connected by, and physically in contact with, the same conductor 340, 350, although, as noted below, a conductor 340, 350 may be in electrical and physical contact with at least one other set of batteries, oriented with the opposite polarity as the first set, thus forming a series connection between the sets.

[0174] Conductors 340, 350 are used to connect the set of batteries 310, 312 in contact with the brackets in parallel with the other batteries of the set, and optionally in series with another set. This may be accomplished by inverting the batteries in an adjacent set and using a single conductor 340, 350 to connect all of the batteries at one end of each set. When this arrangement is used, the batteries in the first set are connected in parallel with each other, as well as in series with the other set. Adjacent sets of batteries may be alternately positioned, with a conductor 340, 350 spanning both sets of batteries on one side, though all the batteries in one set will contact the same conductor with a different polarity from all the batteries in the other set.

[0175] As noted above, batteries, spacers or both may be the primary means of connecting and supporting substrates. However, in another embodiment, perimeter and divider walls are used as one method or the primary method to connect and support the substrates. Referring now to FIG. 11, the substrate shown in FIG. 1 is shown with perimeter and divider walls according to one embodiment of the present invention. A perimeter wall 1110 is attached to substrate 1112. Attachment may be made by means of glue, heat bonding or melting of the wall 1110 to the substrate, or conventional snap together methods or other fasteners via fasteners 1114. Perimeter wall 1110 may be made of several pieces, with edge or corner connectors connecting each of the pieces. Perimeter wall 1110 may contain connectors such as connector 1116,
which may be a slot or other fastener molded into the perimeter wall 1110. Connector 1116 attaches to a divider wall 1118, which may be attached to the substrate 1112 in the same manner as perimeter wall 1110. As shown in the figure, divider walls such as divider wall 1118 may itself have connectors that hold up still other divider walls.

[0176] In one embodiment, perimeter walls 1110 are used to physically protect batteries from outside intrusion, and divider walls 1118 are used to protect batteries, that may be pushed via an unwanted external force, from pushing other batteries nearby, and may also confine any unwanted thermal reactions to a subset of the batteries bounded by one set of walls 1110 or 1118. In addition, because the side walls of the batteries are connected to the negative terminal, and negative terminals of adjacent batteries may be at different potentials from one another, the use of divider walls 1118 can help prevent short circuits that would otherwise occur if the batteries, having different electrical potentials of their respective cases were to touch cases due to an unwanted force. In one embodiment, either a divider wall or a cooling tube (described below) is used to separate adjacent batteries having negative terminals and cases at differing potentials.

[0177] FIG. 5 shows 5 batteries 500-508 connected in series to increase the voltage to approximately five times the voltage of one battery via conductors 520-530 using the technique of the present invention (the substrates, brackets, and spacers have been omitted from the Figure to improve the clarity of the Figure). Although there is only one battery 500-508 in each set in FIG. 5, more than one battery per set connected to the same pair of conductors 520-530 and using the same polarity as each battery 500-508 shown could have been used to increase the current to an approximate multiple of the current of the single battery 500-508. In one embodiment, end conductors 520, 530 have terminals 540, 542, which may be screw terminals or an embedded screw post with a nut that is screwed over the screw post. A wire may be attached to each terminal 540, 542 in a conventional manner to allow power from the battery to be brought to a point of use. The point of use may be an electric motor in an electric car in one embodiment of the present invention, and there may be more than one terminal 540, 542 per end conductor 520, 530, such as is described below. It is noted that in the Figure, conductors 520-530 collectively contact all of the batteries from which current through each conductor 520-530 is provided, but individually, the conductors 520-530 do not contact all of the batteries 500-508 and each conductor 520-530 is at a different electrical potential from the others relative to any other one of the conductors 520-530.

[0178] As shown in the Figure, an odd number of sets of batteries (in the Figure, there is one battery per set) will cause the end conductors 520, 530 to be located on opposite sides of the batteries 500-508. Having an odd number of sets, where the sets are connected to one another in series as shown, can produce a useful assembly 500 of batteries 500-508 because the assemblies themselves can be coupled in series with a minimum of interconnection. If the sets of batteries are arranged in a pattern that causes the first set and the last set to be near each other (such as if the sets are arranged in a somewhat circular pattern around the assembly, the end conductors can be on opposite sides of the assembly, in the same general region, but without significant cross connection structures, allowing interconnection of assemblies with a minimum of cross connection runs.

[0179] The batteries sandwiched by substrates and inserts and connected by conductors as described herein may have insulating paper or other insulating material attached thereto, and multiple such assemblies or structures of batteries may be electrically interconnected. FIG. 6A illustrates the end conductors 636, 637 of two different structures, similar to the end conductors 530, 520 of FIG. 5, each coupled to one or more sets of batteries arranged as described above with respect to FIGS. 1-5, with the detail showing the batteries, substrates, remaining conductors and other structures omitted in the Figure to show the interconnections between end conductors of two different structures (the word structure and assembly are used interchangeably herein). End conductor 636 is an end conductor of one structure, and end conductor 637 is an end conductor of another structure, with the structures intended to be electrically connected in series to one another using expandable connector 650.

[0180] Referring now to FIG. 6A, end conductors 636, 637 have a portion rising above the substrate sandwiched between the end conductors 636, 637 and the batteries to which the end conductors 636, 637 are coupled, such portion being illustrated above the dashed line in the Figure, said line representing the top of the substrate. In one embodiment, U-shaped holes 634 are milled into, or formed as part of, the end conductors 636, 637 to allow insertion of terminals 638 of a connector 650 to be inserted therein, when the connector 650 is inserted in the direction of the arrow. Terminals on the opposite side of expandable connector 650 are not visible, but are the same in number as the visible side, and offset from those on the visible side. In one embodiment, there are more U-shaped holes 634 than terminals 638 on one side of the expandable connector 650 to allow each end conductor 636, 637 to operate on either side of connector 650. Terminals 638, which may be bolts or screws are then tightened over the end conductors 636, 637 to cause a connection between the end conductors 636, 637 and an expandable conductor 640 made of copper or another conducting material. Expandable conductor 650 is a flat conductor bent in a U cross section, and flexible enough to expand when terminals 638 are tightened.

[0181] Expandable connector 650 is shown in greater detail in FIG. 6B. Referring now to FIG. 6D, expandable connector 640 has three primary sets components. There are two expansion pieces 610, one expandable conductor 640 and six terminals 638, though other numbers of terminals may be used.

[0182] Expansion pieces 610 are shown in greater detail in FIG. 6B. Referring now to FIG. 6B, one embodiment, expansion piece 610 has multiple ledges 616, each ledge 616 containing a recessed well 612 that holds a nut and prevents it from turning, and may be a tight enough fit to hold the nut in place in the well 612. The well 612 is about as deep as the nut is thick. Each well 612 has a hole drilled or formed into the center of the well and extending straight through to the opposite side of the ledge 616. FIG. 6B shows a ledge in greater detail. A nut 630 has been inserted into the well and a bolt 632 has been inserted from the opposite side of the ledge 616 from the side from which the nut was inserted 630 through the hole in the well and threaded into the nut 630. As noted below, in practice, the nut will be inserted through a hole in the expansion conductor 640, which is not shown in FIG. 6B.

[0183] Referring now to FIGS. 6B-6D, to assemble the expandable connector two expansion pieces 610 are mated together, facing one another so that their ledges 616 are in a single plane, but having their wells facing 180 degrees away from one another. The expansion conductor 640 is slipped
over the ledges 616 and bolts or screws are inserted through holes in the expansion conductor and through a hole 614 in the ledge 616 until they reach the nuts 630 at the opposite side of the ledge 616, and are screwed part way into the nuts 630. Referring momentarily to FIG. 6A, the expansion connector 650 is slipped between two end conductors as shown in FIG. 6A, and the screws or nuts 632 are tightened.  

When the screws or bolts 632 are tightened, they pull the ledges 616 of the expansion connectors 610 apart from one another in opposite directions, with the face of the ledge opposite the well 612 pressing against the nearby area of the expansion conductor 640 to press it into contact with the edge connector 636, 637, providing an electrical connection that can carry significant current and is physically stable, yet can be disassembled and reassembled as necessary.  

Expandable conductor 650 is described herein as connecting two structures in series. However, expandable conductor may be used to connect multiple structures in parallel as well.  

In one embodiment, the batteries may be liquid cooled via small, thermally conductive tubes through which water or another coolant, such as any conventional anti-freeze mixed with water, oil, or even cold air, may be circulated via conventional means such as a pump.  

The tubes absorb heat from the batteries and transfer it to the liquid, coolant or air. The pump may pump the liquid to a radiator where the heat is released to the air near the radiator, or to a heat exchanger that exchanges heat with a refrigerant, such as conventional R-134a, that operates as part of a conventional heat pump, which absorbs heat from the coolant or other liquid and releases it to a radiator. In the event that the batteries are powering an electric car, the radiator may be drawn through the ambient air when the car is in motion to enable additional heat to be released into the air.  

FIGS. 8A and 9 illustrate the coolant-containing tube, from different perspectives: FIG. 8A is a top view and FIG. 9 is a side view of a different set containing a different number of batteries, but is similar to what would be seen by looking from the third row of batteries from the top of FIG. 8A towards the second row of batteries from the top of FIG. 8 to show the detail not visible in FIG. 8A. FIG. 9 is actually superimposed on the batteries shown in FIG. 5. In one embodiment, one tube 810 is arranged to run near each battery (the position of each battery will roughly correspond to the circles of FIG. 8A) in one or more sets. Referring now to FIGS. 8A and 9, in one embodiment, the tube has an inlet 812 for accepting the liquid, which runs near each of the batteries that it will cool, and then, in one embodiment, the tube turns around via a turnaround section 910 shown in FIG. 9 and runs past each battery a second time, either on the same side of the battery as the first run, or on the opposite side. The turnaround section 910 may be outside of the substrate, for example, near inlet 812, to avoid a joint (between turnaround section 910 and the remainder of the tube 810) being near the batteries. Conventional heat conductive, but not electrically conductive, potting compound (not shown) or another heat conductive substance, such as KONA 8701-LV-1P heat conductive compound commercially available from Resin Technology Group, LLC, may be poured over the tubes so that it also touches the batteries and helps conduct heat from the batteries to the tubes.  

The direction of flow of the coolant in the tubes is shown by the arrows in FIG. 9. An outlet (directly over the inlet 812 in one embodiment) exhausts the coolant to the radiator 814 where the coolant releases its heat, with the coolant being circulated by pump 820. Because two runs of the tube are used near each battery, with the flow of coolant in the tubes running past each battery being in opposite directions and in the opposite order, the batteries may be cooled more evenly than if a single run were employed. In one embodiment, the two tubes are actually part of a single structure, to allow the heat from the two tubes to be exchanged, further stabilizing the temperature of the coolant in the tubes across the run of the tubes. Referring now to FIG. 8C, a single structure 860 containing two tubes is shown according to one embodiment of the present invention. The structure 860 contains crosspiece 864, and may be formed as part of a single extruded piece of aluminum or another heat-conductive material. The crosspiece 864 and structure 860 form the two tubes 862, 866 having opposite directions of flow. In one embodiment, the top tube 862 is coupled to the inlet and in another embodiment, the top tube 862 is coupled to the outlet, though other embodiments may reverse those connections.  

In one embodiment, the outer surfaces of the tubes are made of an electrically insulating material so as not to cause shorts between the cases of the batteries, which are electrically connected to the negative battery terminal. Because the negative terminals of different batteries are at different electrical potentials, if the tube touches the batteries, a short could occur if a tube were made of an electrically conductive material. In one embodiment, the tubes are made of aluminum and the outer portion is anodized to cause the outer edges of the aluminum to be a poor conductor.  

In one embodiment, instead of a radiator absorbing the heat from the tubes and their contents, in the case of an at least partially electric-powered car or other vehicle, heat from the tubes and their contents may be absorbed by an evaporator in a conventional air conditioning system. Referring now to FIG. 8I, a system for cooling batteries is shown according to one embodiment of the present invention. Elements 810-820 operate as described in FIG. 8I above, except that instead of releasing heat to a radiator 814, heat from the batteries absorbed by the coolant in the tubes is released to a conventional evaporator 834 in a heat exchanger 836. Compressor 830 compresses a refrigerant and provides it to a condenser 840, which may be placed near a fan 842 or other airflow. The refrigerant arrives into an accumulator and is provided to the evaporator 834 and returned to compressor 830. A heat exchanger 836 allows the evaporator 834 to absorb heat from the tubes, after the coolant has passed by some or all of the batteries. In one embodiment, a single compressor is used to not only cool the batteries, but also the air in the passenger compartment. A second evaporator 844 absorbs heat in air provided to the passenger compartment via a blower 846 and the refrigerant then collects in the accumulator 838. A diverter valve under control of a microprocessor 850 having sensors 852, 854 to sense the temperature of the batteries and the air in the passenger compartment determines the proper amount of refrigerant to allocate between the evaporator 834 serving the batteries and the evaporator 894 serving the passenger compartment air, based on the temperatures and the requirements of each system.  

The batteries in each set may be air cooled via spaces between the batteries in between which air can blow through. Air cooling may be used in addition to the liquid cooling described above, or in place of it. In one embodiment, inserts to be added to the substrates are used to mount the batteries using integrated cooling holes and mounts as are
described more completely below. The substrate is made of a glass-fiber-containing material for strength and rigidity, yet the insert is made of a more flexible material for better battery holding properties. Both the substrate and the inserts contain air holes into which air may be blown, or out of which air may be removed through suction, or both. The air holes may be integrated with the mounts, so that the air can blow directly into the spaces between the batteries, and yet the mounts do not interfere with the air cooling.

[0195] Referring now to FIGS. 10A-10D, a portion of an insert 1016 including integrated mounts 1018 with integrated air cooling holes 1012 in each of the mounts 1018, is shown according to one embodiment of the present invention. In one embodiment, insert 1016 is placed between the substrate and one or more batteries, although in another embodiment, the features of insert 1016 are part of the substrate. In one embodiment, insert is made of any flexible, insulating material and may be different from or, the same material as, the substrate.

[0194] FIG. 10A is a top view of a portion of a portion of an insert 1016 with batteries, such as battery 1008 inserted into the mounts 1018. In one embodiment, some mounts are shared between two or three batteries, such as the mount shown in the center of FIG. 10A. In one embodiment, each mount 1018 has the shape of a short hollow tube that is molded above a hole running through the insert 1016, with the hollow portion running perpendicular to the substrate 1016.

[0195] A flat cross piece 1010 may be molded between pairs of mounts 1018 just outside the space for the battery 1008 to add strength to the mounts. In one embodiment, cross piece 1010 does not extend the entire distance between nearby mounts, but instead runs a very short distance (about ¼ of that shown), with only one cross piece per mount instead of the three shown. When air cooling is to be used, each of the mounts is over a hole in the substrate to allow air to flow through the substrate 1016 in the direction indicated by the arrow. In another embodiment, shown with the assembly 1061 on the right, duct 1056 is not used, and fan 1059 draws air through the top of assembly 1061. In another embodiment, shown in FIG. 10E, air flows in the direction indicated by the arrow (or in the opposite direction) through multiple assemblies 1074 having air holes as described above via fan 1070 and cowell 1072. Any space between assemblies 1074 may be covered by ducting.

[0200] In one embodiment, the conductors are not adjacent to the substrate, and so a large number of smaller holes may be provided in the conductors to allow air to flow through the conductors generally, but the holes need not be positioned adjacent to a mount in the insert. In such embodiment, the density of holes may be greater around the periphery of the conductor than it is at the center, so as not to interfere with the current carrying capacity of the conductors at locations of high current.

[0201] Although the geometries described herein may be used in one embodiment, other embodiments may employ other geometries. For example, in a non-air cooled environment, the mounts need not be mounted over holes in the substrate.

[0202] Part of an example assembly according to the present invention is shown in FIG. 12A according to one embodiment of the present invention. FIG. 13 describes the method of assembly.

[0203] Referring now to FIGS. 12 and 13, a substrate 1210 is shown with multiple inserts 1216 muted thereto via keys in the inserts 1216 fitting holes in the substrate 1210, corresponding to step 1310. A tubing assembly 1214 is fashioned into shape, for example by bending 1312, and placed 1314 over the inserts 1216.
In step 1316, perimeter walls 1218 are mounted or bonded to the substrate 1210, and divider walls 1220 are inserted between the perimeter walls and may be mounted or bonded to the substrate 1210.

[0205] Batteries, not shown, are added 1318 to the mounts in the inserts as described above and potting compound or other thermally conductive material may be added to touch each of the batteries and the adjacent section of the tube, and then in step 1320, a mirror image set of inserts, not shown, are in step 1322, are mounted to a mirror image substrate, not shown, and mounted to the batteries via mounts and to walls 1216, 1218 as described above.

[0206] Brackets are connected to conductors 1324 and then connected to the batteries 1326 as described above, offsetting over two sets of batteries, each set having an opposite polarity, to connect the two sets in series, for example. An assembly showing an alternate design, including some of the batteries 1222 and the mirror image substrate 1224 is shown in an exploded view in FIG. 12B. Because FIGS. 12A and 12B are water cooled, the air holes in the substrate near the mounts are not employed.

[0207] If there are additional assemblies 1328, they are built as described in steps 1310-1316 and then connectors may be connected 1330 between the edge connectors of adjacent assemblies as described above.

[0208] The steps of FIG. 13 may be performed in different order than what is described, or may be interlaced with one another, mounting the batteries and the walls a few at a time, for example.

[0209] Referring now to FIG. 14, a method of mounting and electrically connecting batteries is shown according to one embodiment of the present invention. One or two or more substrates with mounts for each battery and holes for electrical connection to the batteries are provided 1410. In one embodiment, the mounts are molded into the substrate. In another embodiment, the mounts are milled into the substrate, as described above, and will now be described with reference to FIG. 15.

[0210] Referring momentarily to FIG. 15, a method of milling battery mounts into a substrate is shown according to one embodiment of the present invention. A first position is selected 1510 and a spinning bit is drilled 1512 part way into the substrate at the first position. A petal is milled 1514 by radiating the drill bit outward from the center of the first position, for example, along a line. The bit is brought back to the center of the first position, and another petal is milled 1516 outward from the center of the first position along any line different from (though potentially 180 degrees from) a line used to mill any other petal for that mount. If there are more petals to mill 1518, the method continues at step 1516 and if not 1518, if there are more positions on the substrate in which a mount is desirable or required 1520, the next position is selected 1526 and the method continues at step 1512 as described above, and otherwise 1520, holes may be drilled through the substrate into the center of some or all of the mounts 1522 to provide electrical access and the method terminates 1524. As noted, batteries may be inserted into the mounts as described below, and the holes drilled in step 1522 may be smaller than the diameter of the positive terminal of the battery to be inserted, so as to protect it from coming into contact with a conductor that may be pushed against it.

[0211] Referring again to FIG. 14, multiple batteries are inserted 1412 into the mounts at one substrate, such as the bottom or the top, with one battery per mount in one embodiment. The batteries are inserted as part of sets: the batteries in each set may be inserted with the same polarity of the battery inserted into the mount, but each set may be inserted with polarities inserted that are different from the one or two sets that will be electrically adjacent to it. Spacers may be inserted 1414 into mounts which may or may not be different from the mounts used for the batteries (e.g. the mounts used for the spacers may be narrower than the mounts used for the batteries). In the flowchart, step 1414 follows step 1412, but the two steps may be performed together, with some batteries being inserted and then one or more spacers, then more batteries and one or more additional spacers, etc. Other steps in the flowchart of FIG. 14 or 15 may be performed in this intertwined fashion with other steps or some steps may be performed in a different order than is shown.

[0212] One or more cooling tubes may be run 1416 among a path adjacent to some or all of the batteries and the same one or more cooling tubes or a different one or more cooling tubes may be run 1418 back in the opposite direction along the same path or an opposite path. Steps 1416 and 1418 may be combined by running a single cooling tube assembly near each battery. In this manner, each battery is adjacent to two flows, with one in either direction, although other numbers of one or more flows in any number of directions near each battery may also be used. A heat conductive material may be added 1420 to contact the tube or tubes and some or all of the batteries.

[0213] Another one or more substrates may be pressed 1422 on to the other end of the batteries that were inserted in step 1412 and the spacers inserted in step 1414 using a conventional press. The other one or more substrates are made with the mounts described above. The mounts may be differently sized depending on the polarity of the battery the mount will accept, or the same sized mount may be used for all polarities. The other one or more substrates of step 1422 may be mirror images of the one or more substrates of step 1414.

[0214] Multiple conductors with holes are provided 1430 as described above. Brackets may be inserted 1432 into the holes and each bracket may be electrically connected 1434 to a conductor, such as by wave soldering the brackets to the connector when most or all of the brackets are in the holes of the connector.

[0215] The brackets with the connectors and the batteries mounted in the substrates described above are brought together in steps 1436 and 1438, which may be performed essentially simultaneously, but will be described separately for ease and clarity of description. One or more brackets electrically attached to the conductors are electrically attached 1436 to one or two sets of batteries via the holes in the substrates. This may be performed by aligning the brackets protruding out of the holes in each of the one or more conductors, with the holes that expose the terminals of the batteries mounted in one or more substrates.

[0216] The alignment may cause each conductor to electrically connect one terminal of each battery in a set to the same polarity terminal of all of the other batteries in a set, and optionally to also connect to such terminals the terminals having the opposite polarity of all of the batteries in a different set. For example, if all of the batteries mounted in the substrate are to be divided into sets, and all of the sets are to be connected in series, there will be one conductor spanning one end of each two electrically adjacent pair of sets, with the ends of each set spanned by a single conductor having opposite polarities, and two additional conductors, each spanning one polarity of all of the batteries in one of the two “end” sets.
Thus, in one embodiment, all but one or two of the conductors are each aligned over the terminals of two complete sets of batteries, the batteries in each set being connected at the same polarity with the other batteries in the set by the brackets and conductors when placed in contact thereto. Two sets of batteries may be connected to the same conductor, with each of the two sets having opposite polarities being connected to the conductor. In one embodiment, the electrical attachment also includes a physical attachment, such as by spot welding, pressure contacting or low-temperature soldering each bracket to one terminal of each of the batteries. In one embodiment, each bracket has two or more connections (e.g. spot welds) to at least most of each of the battery terminals for redundancy.

A process similar to the process described above is repeated for the one or more substrates on the other side of the batteries 1438, with brackets attached to one or more conductors as described above with respect to steps 1430-1434 aligned to fit into the holes in the substrate of the opposite side of the substrate of step 1436 and the brackets are spot welded to, connected, or otherwise electrical brought into contact with, the terminals inserted into the mounts of that substrate. As noted herein, any conductors spanning two sets of batteries are offset from those of the other substrate so that zero or more conductors can each connect the different polarity terminals in each of two sets of batteries in series, and will, in part, connect the batteries within the set in parallel. It isn’t necessary to weld the brackets to the batteries: any electrical connection between the bracket and battery terminal can be used.

The conductors at the ends of each series of sets of batteries may be coupled 1442 to one or more edge terminals and the one or more edge conductors of one pair of substrates that make up a battery assembly may be connected 1440, either physically, electrically or both, to an edge conduction of an adjacent pair of substrates that make up a battery assembly (each assembled as described above), so as to connect at least some of the batteries in each assembly in series or parallel. In one embodiment, step 1444 is performed via a single solid, but slightly flexible unit, which may be constructed without wires.

FIG. 16A is a side view of a portion of battery pack 100A according to one embodiment of the present invention. Referring now to FIG. 16A, batteries 110A and 112A are conventional rechargeable batteries such as Lithium-ion or Nickel metal hydride batteries. Substrate 118A and substrate 120A, in which the batteries are mounted, are described in the related application. Conductor 150A and conductor 140A are sheets of hole-punched copper layered over the substrates 118A, 120A, with holes in each conductor aligned over the ends of each battery. Substrates 118A and 120A serve to hold the batteries and prevent the batteries’ positive and negative terminals from touching conductors 150A and 140A, respectively.

The batteries’ positive terminals 114A are connected to conductor 150A by fusible links, such as wire bonds 144A, and the batteries’ negative ends 116A are connected to conductor 140A by similar fusible links, such as wire bonds 142A via holes in the substrates 118A, 120A and conductors 140A, 150A. These wire bonds are one method of fusibly linking each battery to each conductor, and are described herein as a representative example; other methods of fusibly linking each battery to each conductor may be used in other embodiments. In one embodiment, each wire bond is a wire 15 mils thick, made substantially of Aluminum. The wire bond is made of an aluminum alloy containing 50 parts per million of nickel for corrosion resistance and one-half of one percent of magnesium for added strength. The batteries are conventional.

The current carrying capacity of wire bonds 144A and 142A is slightly greater than the maximum expected current from one battery. In the event that the current carrying capacity is exceeded, the wire bond for that battery will break sufficiently to ensure that no arcing will occur; preventing the current from flowing through the battery 110A or 112A and the conductor 140A, 150A, and allowing the rest of the batteries in the pack to continue to function in the event of an overcurrent condition, such as a short circuit through the battery.

FIG. 16B is a top view of the battery pack 100A of FIG. 16A according to one embodiment of the present invention. Referring now to FIG. 16B, wire bonds 144A are connected in parallel to conductor 150A via holes 160A in the conductor 150A and underlying substrate (not shown). Conductor 150A may be cut to any shape to fit the arrangement of batteries in the available space.

FIG. 17 is a block schematic diagram of a set of two battery packs and a fuse according to one embodiment of the present invention. Referring now to FIG. 17, each battery pack 100AA, 100AB is constructed in the same or similar manner as battery pack 100A as described with reference to FIGS. 16A and 16B. Fuse 210A connects the conductor that is wire bonded to the positive ends of the batteries in battery pack 100AA to the conductor that is wire bonded to the negative ends of the batteries in battery pack 100AB.

The current carrying capacity of fuse 210A is just below the current carrying capacity of the sum of the wire bonds coupled to one conductor, or just above the maximum expected current through all the batteries in each pack 100AA, 100AB. In the event that the current carrying capacity of fuse 210A is exceeded, fuse 210A will blow, preventing the current from blowing out the wire bonds in the battery packs 100AA, 100AB, for example, in the event that a short occurs between terminals 220A and 222A.

Although fuse 210A is shown in this embodiment between the battery packs, in other embodiments it may be placed elsewhere, such as in front of, or behind, the series of battery packs 100AA, 100AB. Any number of battery packs 100AA, 100AB may be fusibly connected, in serial, in this manner. Terminals 220A and 222A end the chain of battery packs and the fuse 210A.

One or two or more of battery packs 100AA, 100AB with the fuse 210A may be added to a conventional hybrid or electric vehicle, such as an automobile or rocket to manufacture such a vehicle. Other products may be manufactured using one or more such battery packs, with or without fuse 210A.

FIG. 18 is a flowchart illustrating a method of fusibly coupling batteries according to one embodiment of the present invention. Referring now to FIG. 18, multiple batteries are mounted in substrates 310A. The positive ends of the batteries are mounted in one substrate and the negative ends of the batteries are mounted in a second substrate, as described above. The substrates are described in detail in a related application.

Each substrate is layered with a conductor 312A. Each conductor is placed on the side of the substrate that does not touch the batteries, so that the batteries and substrates are
sandwiched between two conductors, as described above. As previously described, the conductors are sheets of copper that
contain holes, and each hole is aligned over one end of one
battery.

[0230] When the substrates have been sandwiched with
collectors, the positive ends of each battery are fusibly
linked to one conductor, and the negative ends of each battery
are fusibly linked to the other conductor 314 A. As previously
described, in one embodiment, the fusible links are wire
bonds that run through the holes in a substrate and conductor.

[0231] When each battery has been fusibly linked to each
conductor, the battery pack is complete. As described above,
two or more battery packs may be connected. In one embodi-
ment, to connect two battery packs, the packs and a fuse
are connected in series as described above 316 A. Any number
of battery packs and fuses may be serially connected in this
manner. As used herein, a battery pack is a set of one, two,
or more batteries in which some or all of the terminals of one
polarity are connected to one conductor and some or all of
the terminals of the other polarity are connected to another
conductor.

[0232] FIG. 19 is a block schematic diagram of a system
of interconnected battery packs according to one embodimen-
t of the present invention. FIG. 19 shows parallel interconnected
battery packs, but battery packs may be connected in series as
is shown in FIG. 21, and battery packs may be connected in
series and parallel as is shown in FIG. 25.

[0233] Referring now to FIG. 19, battery pack 112 B is
electrically coupled via flexbus bars 130 B, 150 B to bat-
tery pack 114 B. Battery pack 114 B is similarly coupled elec-
trically to battery pack 116 B. In one embodiment, each pack
112 B, 114 B, 116 B is adjacent or nearly adjacent to each of
the other packs 112 B, 114 B, 116 B. In one embodiment, each
battery pack 112 B, 114 B, 116 B consists of a set of battery
bricks connected in series as described below. Each battery
brick is a set of batteries connected in parallel to one another,
as described below. The battery bricks are not separately
shown in the Figure, but are shown in the related application
as sets of parallel-connected batteries.

[0234] Battery pack 112 B is selected as a representative
pack, but packs 114 B and 116 B are constructed in the same
manner. Each terminal 130 B, 140 B of battery pack 112 B is a
metal connector on the outside edge of battery pack 112 B.
Each terminal 130 B, 140 B is connected to one of the termi-
nals of the brick at the edge of the set of bricks. Each terminal
130 B, 140 B extends from a side of the pack 112 B, such as the
top or bottom, and then folds over to a plane parallel to
another side of the pack. The first side may be open so that
the batteries are exposed to view, access or both, and the other
side may be sealed so that the batteries are not exposed to
view or access. The open side permits the terminal 130 B,
140 B to extend from the pack 112 B without interference and
the second side prevents screws intended for the terminal
130 B, 140 B from falling into the pack 112 B.

[0235] A flexible bus bar 150 B connects external terminal
140 B of battery pack 112 B to an external terminal of battery
pack 114 B. In one embodiment, flexible bus bar 150 B is a
conventional mesh-like, flexible ribbon or tube of multiple,
thin wire strands which allows a very high current carrying
capacity while reducing the danger of stresses and fractures
to the assembly. In one embodiment, flexible bus bar 150 B is a
conventional flexible bus bar, such as may be fabricated using
conventional ground braids, such as the conventional FTCB
15-35 ground braid with a crimped-on lug commercially
available from Erico, of Solon, Ohio (at the website of Erico.
com). The extreme flexibility of flexible bus bar 150 B relative
to ordinary electric facilities that can carry a similar current as
that which can be carried by the flexible bus bar 150 B is
advantageous in a high vibration environment, such as the
engine of a car, because the wiring will not break or fracture
itself, or the components to which it is connected, as those
components vibrate or move relative to one another. A non-
flexible method of wiring, particularly a non-flexible method
of wiring that is expected to carry high levels of current like a
solid conductor, could fracture or break, or induce fractures
or breaks in the packs 112 B, 114 B, 116 B.

[0236] Battery pack 114 B and battery pack 116 B are
coupled to one another in a similar manner, and any number
of additional battery packs may be coupled to one another in
this manner. FIG. 19 illustrates battery packs coupled in par-
allel; however, as shown in more detail in FIG. 21, battery
packs may also be coupled in series using the flexible bus bar
arrangement described herein. Other arrangements could
couple some battery packs in series and others in parallel,
according to the voltage and current needs of the device or
devices that use the current and voltage supplied by the bat-
tery packs 112 B, 114 B, 116 B.

[0237] Referring now to FIG. 21, a set 300 B of intercon-
ected battery packs 312 B, 314 B, 316 B is shown according
to another embodiment of the present invention, and a flexi-
ble bus bar 390 B is shown in more detail. Battery packs 312 B,
314 B, 316 B are similar to battery packs 112 B-116 B shown in
FIG. 19. As described in the related application Ser. No.
11/29,118, the series connections of each brick in a battery
pack such as battery pack 316 B is made via a solid conductor
spanning two bricks. Each brick has a set of batteries orient-
ed in the same polarity, but opposite to that of the electrically
adjacent brick. Thus, the batteries in each brick are oriented
upside down relative to the batteries in the adjacent bricks.
A single solid conductor not only connects one of the polarity
terminals one set of batteries in one brick to one another in
parallel, but many of them extend to also connect the opposite
polarity terminals of another set of batteries in an adjacent
brick to one another in parallel. The effect of using this single
conductor is to connect the two sets of batteries in series to
one another. For example, a conductor can be in electrical
contact with the positive terminals of the batteries in brick 1,
as well as the negative terminals of the batteries in brick 2,
connecting brick 2 in series with brick 1. There may be any
number of series-connected bricks in a battery pack, though,
as mentioned above, in one embodiment, the number of
bricks is nine. Each brick in a given battery pack is therefore
adjacent to any other brick to which it is directly connected in
series in this manner.

[0238] The conductors at either end of the series of bricks
contact just the conductors of one brick. So, using the
example above, if brick 1 is the end of the series of bricks, the
negative terminals of the batteries of brick 1 may be elec-
trically connected via a conductor, which is coupled to the edge
terminal of the battery pack. For example, conductor 324 B,
shown in the Figure, may be the negative terminal for the
battery pack. (The remaining conductors are not shown to
avoid cluttering FIG. 21, but are shown in more detail in
FIGS. 22 A and 22 B.) In one embodiment, the conductor
324 B is electrically connected to, or forms, a terminal 320 B,
which is used as the negative terminal for the battery pack.
316 B. In one embodiment, terminal 320 B is actually a part of
conductor 324 B, formed by bending a tab extending from
conductor 324B at a 90 degree angle, although other embodiments may have an electrical connection such as a weld. Each of the battery packs 312B-314B may use a similar construction as that described above for battery pack 316B.

[0239] In one embodiment, the flow of current through the battery bricks, looking at the narrow side, would be seen as back and forth through adjacent sets of parallel-connected battery bricks. However, when viewed from the flat face of the pack 312B-316B, the flow of current is circular, starting at one terminal, such as terminal 322B and ending up at approximately the same position (though on the opposite face as the current started). This enables the two terminals on the battery pack to be located at the same height as one another, allowing for short series connections between adjacent battery packs 312B-316B. This is achieved via placement and shape of the conductors within each pack, as will now be described.

[0240] Referring now to FIGS. 22A and 22B, an arrangement of the conductors on either side of a battery pack are shown according to one embodiment of the present invention. Conductors 410B, 414B, 418B, 424B and 428B are on the far side of substrate 400B and conductors 412B, 416B, 420B, 422B, 426B and 430B are on the near side of substrate 402B. When substrate 402B is placed behind substrate 400B and sets of batteries are placed between them, the conductors and batteries form an electrical connection from edge 450B to edge 452B or vice versa. For example, the positive terminals of a set of batteries are electrically connected to conductor 410B, such as may be described in the related application. The positive polarity terminals of that same set of batteries are electrically coupled to the lower half of conductor 412B. Negative terminals of another set of batteries are electrically coupled to the upper half of conductor 412B, and the positive terminals of that other set of batteries are electrically coupled to the right half of conductor 414B. Thus, the two sets of batteries are connected in series to one another. Multiple sets of batteries are coupled in this manner via the conductors 410B-430B, with current flowing in numerical order of the conductors, or in reverse order, with the resulting flow being circular when viewed from the flat face of the pack. However, conductors 420B and 422B operate as a single conductor, with fuse 440B electrically coupled between them to electrically protect the batteries as described in the related application. In one embodiment, a bus bar similar or identical to that described herein is used in place of fuse 440B in the event that fusing is not desired or required.

[0241] End 450B of edge conductor 410B and end 452B of edge conductor 410B is folded 90 degrees to form a terminal, in a manner similar to that shown for terminal 320B of edge conductor 324B of FIG. 21. Referring again to FIG. 21, the terminal of one pack 312B, 314B, 316B is electrically connected to the nearest terminal of another pack 312B, 314B, 316B using a flexible bus bar 390B, for example, as shown between packs 314B-316B. No flexible bus bar is shown between packs 312B and 314B, but one could be installed there if a series connection between the two packs 312B, 314B was desired. Any number of packs may be connected using any manner described herein.

[0242] In one embodiment, the flexible bus bar 390B is made of a conventional braided conductive metal 350B, such as copper or aluminum, onto which conductive terminals 360B, 370B may be crimped or otherwise electrically connected. Each terminal may have a hole, such as hole 380B, to accept a screw, which is inserted through hole 380B, and threaded into a hole 322B in terminal 320B of any battery pack. The hole 322B may be threaded or self tapping screws may be used. When the screw, thus inserted and threaded, is lightened, it physically and electrically connects the terminal 320B to the bus bar 390B. The head 340B from such a screw is shown in the FIG. with the screw head 340B parallel to the face of the pack 312B, the terminal of which the screw is threaded into.

[0243] A similar connection is made to the opposite polarity terminal of the adjacent battery pack using the other terminal of the same bus bar.

[0244] In one embodiment of the present invention, the terminal conductors are shaped to allow series connections, parallel connections or both. Referring now to FIGS. 22C and 22D, the conductors are the same as described above with reference to FIGS. 22A and 22B, respectively, but the terminal conductors 410B and 430B of FIGS. 22A and 22B have been replaced with conductors 411B and 431B of FIGS. 22C and 22D. Conductor 411B has terminal 451B that is folded over the face of the battery pack (or is coupled to a terminal on that face) and conductor 431B has terminal 453B that is folded over the face of the battery pack or is coupled to a terminal on that face. In all other respects, the position of the conductors and flow of current is the same.

[0245] Referring now to FIG. 25, a battery assembly 500B containing four battery packs 512B-518B is shown. Each battery pack 512B-518B is similar to that of battery packs 312B-316B, except that they use the conductors shown in FIGS. 22C and 22D to connect the batteries in each set to another in parallel and to connect adjacent sets of batteries to one another in series. This is in contrast to the battery packs of FIG. 21, which employ the conductors of FIGS. 22A and 22B. Packs 512B and 514B are coupled to one another in series via flexible bus bar 522B and packs 516B and 518B are coupled to each other in series via flexible bus bar 524B. Each pair of series-coupled packs 512B, 514B being one pair and 516B, 518B being another, are coupled in parallel via flexible bus bars 530B, 532B.

[0246] Each of the terminals used for the series connections are at or near the same height relative to the bottom edge of the battery packs 512B-518B. Each of the terminals used for the parallel connections of one polarity are at the same height relative to the bottom edge of the battery packs 512B-518B. The terminals used for the series connections are at a height relative to the bottom edge of the battery packs 512B-518B that is different from the height, relative to the bottom edge of the battery packs, of each terminal used for the parallel connections, and each polarity of the terminals used for the parallel connections are at a different height, relative to the bottom edge of the battery packs 512B-518B from one another. This arrangement ensures that the flexible bus bars remain as short as possible and do not cross one another.

[0247] Insulators (not shown) may be placed over the terminals that flexible bus bars 530B and 532B cross, to avoid a connection between the bus bars and those terminals. In another embodiment, flexible bus bars are insulated. In still another embodiment, the unused terminals are scored just behind the bend, to allow them to be snapped off and removed, so that connection to the bus bar is not possible.

[0248] This manner of extending terminals from the battery packs allows for complete flexibility of connection. The two edge terminals 540B, 542B may be used as terminals for the assembly.
FIG. 20 is a flowchart illustrating a method of connecting battery packs according to one embodiment of the present invention.

Referring now to FIG. 20, a set or sets of batteries are connected in parallel to form battery bricks. To connect the set(s) of batteries in parallel, the method described above, and in the related applications, may be used.

In one embodiment, as described above, battery bricks (e.g., nine battery bricks) are coupled in series to form battery packs 212B. In one embodiment, step 212B includes connecting the battery bricks in such a manner that the terminals will appear at opposite sides of the battery packs as described above. In one such embodiment, current flows back and forth between the opposite sides of the battery pack, and relative to the sides of the pack, flows in a circle around the periphery of the pack as described above. At each end of the series connection, two terminals will exist, one of each polarity.

Packs are stacked adjacent, or nearly adjacent, to one another 214B that will not be between the stacked packs. Battery terminals are extended to the edge of each battery pack 216B. To extend the terminals to the edge of the pack, conductive materials, such as metal plates, are positioned on an outside edge of the battery pack and connected to, or formed into, each of two terminals at the end of the series connection described above to extend the flow of current to the exterior of the battery pack. In one embodiment, the two terminals extend from the top and bottom of the pack, and in another embodiment, the two terminals extend from either side of the pack, and in still another embodiment, there are four terminals as described above: one for series connection and another for parallel connection and each of the terminals for a pack fold over the same side of the pack, to save space and eliminate the possibility that screws will fall into the pack, as described above.

A terminal from one battery pack is connected to one a terminal from at least one other battery pack using a flexible bus bar 218B. To connect the external terminals with a flexible bus bar, each end of the flexible bus bar is physically and electrically connected to the terminals on adjacent battery packs. For example, a screw may be inserted through a terminal connector of the flexible bus bar to a threaded hole on a terminal of the battery pack to connect each end of the flexible bus bar to a terminal of a different battery pack. The multiple, thin wire strands of the flexible bus bar allow a high current carrying capacity with a minimal change of stresses and fractures in the flexible bus bar or battery pack in a high vibration environment, as described above. In one embodiment, the battery packs may be coupled in parallel as illustrated in FIG. 19, or in another embodiment, the battery packs may be coupled in series as illustrated in FIG. 21, in each case via one or more flexible bus bars. In another embodiment, a combination of series and parallel couplings are used. In one embodiment, the current carried by the flexible bus bar is in excess of 30, 50, 100, 150, 200, 250, 300 or 500 amps.

The batteries thus connected may be coupled to the power source of an electric or hybrid vehicle, such as an electric motor of an automobile or rocket 220B.

The method of FIG. 20 may be used to build the battery assembly consisting of two or more battery packs and one or more interconnecting bus bars, and such a battery assembly may be used to build an other products. Such products may include some or all of the power storage and supply of a battery- or hybrid-powered automobiles, rockets or other vehicles 610B of FIG. 24. The steps of FIG. 20 are used to construct the battery assembly, such as those described with respect to FIG. 19, 21 or 23, either in the vehicle, or separately so that it may be added to the vehicle. The remainder of the vehicle may be constructed using conventional techniques.

Referring now to FIG. 25A, a system of battery cells inhibited from thermal chain reactions is shown according to one embodiment of the present invention. The system of more than one battery cell is referred to as an “battery cell pack” or “battery cell assembly”, which means the same thing as used herein and is one form of an “electrical storage pack”. In one embodiment, the battery cells 108C have a substantially cylindrical shape, though any form factor used for storing energy may be used, such as prismatic cells. The battery cells 108C may be any type of energy storage device, including high energy density, high power density, such as nickel-metal-hydride or nickel-cadmium, nickel-zinc, air-electrode, silver-zinc, or lithium-ion energy battery cells. Battery cells may be of any size, including mostly cylindrical 18x65 mm (18650), 26x65 mm (26650), 26x70 mm (26700), prismatic sizes of 34x50x10 mm, 34x50x5.2 mm or any other size/ form factor. Capacitors may also be used, such as supercaps, ultracaps, and capacitor banks may be used in addition to, or in place of, the battery cells. As used herein, an “electrical storage pack” includes any set of two or more devices that are physically attached to one another, capable of accepting and storing a charge, including a battery cell or a capacitor, that can fail and release heat in sufficient quantity to cause one or more other nearby devices capable of accepting and storing a charge, to fail. Such devices are referred to herein as “power storage devices”.

The battery cells 108C, such as battery cell 110C, in the assembly 100C are mounted in one or more substrates, such as substrate 112C, as described in the related applications. There may be any number of battery cells 108C in the assembly 100C. Although only three battery cells 108C are referenced in the Figure to avoid cluttering it, all of the circles are intended to be referenced by 108C. The battery cells 108C are located nearby one another, for example not more than 20 mm center-to-center distance for battery cells 108C that have a maximum diameter of 18 mm. Other embodiments have spacing under one quarter or one half of the center to center distance, making the spacing between the battery cells less than half the width of the battery cell in the plane that spans the center of each pair of battery cells. In one embodiment, the center-to-center distance for the battery cells 108C (measured from the center of a battery cell to the center of its nearest neighbor) does not exceed twice the maximum diameter of the battery cells, although other multiples may be used and the multiples need not be whole numbers. Not all of the battery cells 108C in the system need be spaced as closely, but it can be helpful to space the battery cells relatively closely, while providing adequate space to ensure the thermally-conductive material, described below, has room to be added.

In one embodiment, the substrate 112C is that described in the related application. Briefly, the substrate 112C is a substrate sheet containing holes that are surrounded by mounting structures that hold the battery cells firmly against the substrate, positioned with the terminals of the battery cells 108C over the holes, with each of the battery cells 108C located between two of the substrates. Different substrates such as substrate 112C are located at either end of each of the battery cells and the different substrates in which each battery cell is mounted are located approximately one
battery cell length apart from one another (only one substrate is shown in the Figure, but another one would be pressed onto the tops of battery cells 108C. The radius of the holes is equal to or lower than the radius of the battery cells 108C at the hole.

[0259] The battery cell mounting process involves inserting the battery cells 108C into one or more substrates 112C at one side, such as the bottom. Cooling tubes 114C are added adjacent to each of the battery cells 108C as described in the related application and carry a coolant to absorb and conduct heat, though it is noted that the coolant in the cooling tubes 114C may not be a significant thermal conductor relative to the potting compound described below.

[0260] A thermally-conductive material such as thermally-conductive potting compound or another thermally-conductive material 116C is poured or placed around the battery cells 108C so that the battery cells having 65 mm height are standing in the potting compound or other thermally-conductive material 116C at least to a depth of approximately 6 mm that will cover a part of the battery cells and the cooling tubes. Other embodiments may employ other depths, which may be approximately 5%, 15%, 20%, 25%, or 30% of the height of the battery cell.

[0261] In one embodiment, the conventional Stycect 2850kt, commercially available from Emmeron and Cuming Chemical Company of Billerica, Mass. (Web site: emmeron-cuming.com) is used as the potting compound 116, though any potting compound or other material with a high thermal conductivity can be used. The Stycect catalyst CAT213V is used with the potting compound.

[0262] It is not necessary that the thermally conductive material quickly release heat to the nearby battery cells or the ambient air. In one embodiment, the thermally conductive material absorbs more than a nominal amount of heat. For example, in one embodiment, the thermally conductive material is selected so that at least some of the thermally-conductive material near a battery cell that is experiencing a failure will undergo a phase change, for example, from a solid to a liquid or from a liquid to a gas. For example, the thermally-conductive material may contain a material that will undergo such a phase change and that is micro-encapsulated in the thermally conductive material, allowing the thermally-conductive material to more rapidly absorb additional heat. The heat may therefore be dispersed to the nearby battery cells and the ambient air over time, causing the adjacent battery cells to absorb less heat and to do so more gradually.

[0263] The thermal conductivity of the thermally conductive material 116C poured or placed around the battery cells 108C should be high enough to absorb the heat generated from any battery cell (for example, battery cell 110C) that is venting gases in a worst case scenario and absorb it or distribute it to the air and to many of the battery cells 108C, including those nearest to the battery cell 110C generating the heat as well as others farther away from the nearest battery cells, without allowing any of the battery cells to which heat is being distributed to reach a temperature that would cause a self-sustaining reaction that would cause any such battery cell to fail or vent gases. The thermally-conductive material may also distribute heat to the nearby cooling tubes and coolant contained therein.

[0264] In one embodiment, the potting compound or other thermally-conductive material 116C is poured into the spaces between the battery cells 108C in liquid form, which hardens to a solid or semi-solid material. Although solid materials such as hardening potting compounds can prevent leakage, potting compounds that remain somewhat liquid may be used. The potting compound or other thermally-conductive material 116C contacts the case of each battery cell as well as any nearby battery cells so that heat released from one battery cell due to physical (e.g. crushing), chemical or other causes will be rapidly transferred to many nearby battery cells as well as the potting compound itself and the substrate with which it is in contact. The potting compound or other thermally-conductive material 116C may have electrically insulating qualities or may be conductive. However, in one embodiment, the potting compound is not used solely to conduct electricity, connections on the battery cells being separately provided instead, for example, using the method described in the related application.

[0265] A second one or more substrates are added to the top of the battery cell assembly, and conductors are sandwiched around the substrates as described in the related application.

[0266] FIG. 25B is a side view of two rows of the battery cells after the potting compound has hardened among the battery cells and the tubes. The potting compound 116C will conduct any heat from one battery cell 110C that is overheating to many more of the battery cells than would have occurred if no potting compound was used. Not only is the heat spread to the immediately adjacent battery cells 120C, it is also spread to more distant battery cells 130C, as well as being absorbed by the potting compound 116C itself and optionally substrate 112C before dissipating into the ambient air (as noted, the upper one or more substrates are not shown in the Figure). This effect distributes the heat from the battery cell 110C experiencing the failure, among multiple battery cells 120C, 130C and the potting compound or other thermally conductive material 116C, reducing the heat that will be absorbed by any one battery cell, and thereby reducing the chance that a second battery cell will achieve a temperature sufficient to cause a thermal reaction (which would cause the second battery cell to fail), optionally to the point of venting gases, resulting from the release of heat of the first battery cell.

[0267] FIGS. 25C and 25D are side and top views illustrating battery cells in a thermally conductive material according to another embodiment of the present invention. Referring now to FIGS. 25C and 25D, in this embodiment, the thermally conductive material 150C is a solid, such as a sheet of aluminum or other thermally conductive material. Holes 154C in the sheet 152C are inserted over the battery cells 152C or the battery cells 152C are inserted into holes 154C in the sheet 150C. A bushing 156C or another thermally-conductive material that can thermally couple the battery cells 152C to the sheet 150C is inserted among them to thermally couple each of the battery cells 152C to the sheet 150C. In the case that the sheet is electrically conductive, the bushing 156C can be made of thermally conductive, but electrically insulating material. In one embodiment, potting compound may be used as the bushing 156C. The cooling tubes may be thermally coupled to the sheet 150C.

[0268] Referring now to FIG. 26, a method of manufacturing a chain-reaction-inhibiting battery cell pack and distributing heat generated from one battery cell to more than one other battery cell is shown according to an embodiment of the present invention. Multiple battery cells are mounted 210C in a substrate. One or more tubes containing a coolant such as water, are run 212C adjacent to each battery cell. In one embodiment, the coolant in the tubes runs in both directions past the battery cells, so that the coolant flows between
the battery cells, turns around, and then flows out from between the battery cells in a counter-flow manner as described in the related application. Thermally conductive material such as potting compound is placed 214C in between the battery cells and may contact the tubes and optionally fully or partially hardens or becomes harder among the battery cells and the tubes, contacting the battery cells and the tubes. In the event of a reaction in which heat is generated from one of the battery cells and excess heat is released, for example, via a venting of heat and gases from one or more battery cells 216C, such as could be caused by an internal shorts or a random thermal reaction starting in one or more of the battery cells, the thermally conductive potting compound will draw 218C the heat released from the battery cell to a wide area, wider than would have been likely if no potting compound was used, and will distribute 220C the heat to several of the battery cells, spreading the heat among more battery cells than would have occurred without the potting compound, and reducing the chance that the temperature of any of the adjacent battery cells immediately after the original release of heat will rise sufficiently to cause any such other battery cell to thermally react to the point of full or partial failure, such as by venting heat and gases. Step 218C may include a phase change of at least some of the material in the potting compound as described above.

[0269] Referring now to FIG. 27, a conventional vehicle 410C such as an electric-, hybrid-, or plug-in-hybrid-powered car is shown according to one embodiment of the present invention. The battery cell assembly 320C produced as described above may be added to a conventional fully-, or partially-electric powered vehicle 310C, such as an electric, hybrid or plug-in hybrid car or rocket. The battery cell assembly may be coupled to, and supply power to, an electric motor (not shown) powering the vehicle.

[0270] One or more battery cell assemblies according to the present invention may be used to build a conventional uninterruptible power supply, or other battery back-up device, such as that which may be used for data center power, cell-tower power, wind power back up or other backup power. One or more battery cell assemblies may be used to build hybrid power vehicles or equipment, electrical peak shaving equipment, voltage stability and/or regulation equipment or other equipment.

[0271] FIG. 28 is a flowchart illustrating a method of assembling an electric motor according to one embodiment of the present invention. FIG. 29A is a diagram of an exploded view of a rotor according to one embodiment of the present invention. FIG. 29B is a diagram of a portion of the rotor of FIG. 29A according to another embodiment of the present invention. The method of FIG. 28 is described alongside the diagrams of FIGS. 29A and 29B, however, the rotor and method may be practiced independently of one another. e.g. the method of FIG. 28 may be used on a rotor different from that shown in FIG. 29A or 29B and vice versa.

[0272] Referring now to FIGS. 28, 29A and 29B, laminated steel discs 210D are stacked 110D. A representative disc 210D is shown in more detail in FIG. 30. Referring now to FIGS. 28, 2A, 2B, and 3, in one embodiment, each of the discs 210D is substantially round in shape, and each of the discs has teeth 310D radiating outwards from a central portion. In one embodiment, the teeth 310D have a portion 314D forming a trapezoid that is nearly rectangular in shape, the longest sides being approximately one-half to five degrees out of parallel (e.g. 0.75 degrees), the teeth being slightly wider at the outermost edge than the width at the innermost edge of the trapezoidal portion 314D. In between each of the teeth 310D are spaces 312D that form a substantially triangular shape. The discs 210D are stacked to allow the teeth 310D from adjacent discs to be aligned with one another so that the stack forms spaces 312D between each pair of adjacent teeth 310D, the space 312D forming two sides of a triangle. In one embodiment, a part of each disc 210D is keyed to allow imperfections in the shape of the discs 210D to be matched by any disc above or below it. The triangular shape of the spaces 312D between the teeth 310D take up the larger circumference of the outer portion of the discs relative to their inner portions.

[0273] Bars 212D having a substantially triangular cross section (or another shape that fits in the spaces 312D between the teeth 310D) are inserted 112D into the spaces between the teeth 310D of the discs 210D. In one embodiment, the bars may be tapped into the stack of discs 210D using a rubber mallet. In one embodiment, the teeth 310D have T-shaped ends to hold the bars 212D in place. The bars may be made of copper or made of another material, for example, copper with silver plated ends. Each of the bars 212D is longer than the stack of discs 210D, so that each of the bars 212D stick out from either end of the stack of discs 210D. Between the outer ends of the bars 212D, a space is formed, allowing slugs 214D, described below, to be radially inserted in the spaces between the bars 212D and above and below the teeth 310D of the discs 210D in the manner described below. The spaces between adjacent bars 212D at each of their ends have a nearly square shape, with the faces of adjacent bars 212D being only a small amount out of parallel as described above, and the spaces are wider at the opening of such spaces from the outer portion of the rotor assembly 200D than the width of the spaces nearer to center of the rotor assembly 200D.

[0274] Slugs 214D having a substantially rectangular cross section or another cross section at least similar to portion 314D of teeth 310D, are radially inserted 114D in the spaces between the bars above and below the teeth. As shown in FIG. 31, the slugs 214D have not yet been inserted. The slugs are inserted from their positions shown in FIG. 31 to their positions shown in FIG. 29 by pushing and optionally tapping them with a rubber mallet towards the axis of the rotor assembly 200D. In one embodiment, a disc (not shown) with beveled edges that has a diameter slightly larger than the diameter of the circle defined by the inner edges of the bars 212D nearest the bolt 220D is placed over the bars 212D (and may have a hole to accept bolt 220D to properly center the disc and maintain its position) so that the beveled edge of the disc touches the inner edges of the bars 212D. The slugs 214D are slightly longer than the portion of the bars 212D that extends past the stack of discs 210D so that if the slugs 214D are inserted between the bars 212D directly above or below the stack of discs 210D, the slugs 214D will extend further from the discs than the ends of the bars 212D. Because of this extra length, the disc with the beveled edge will serve as a stop as the slugs 214D are being tapped in towards bolt 220D to ensure that the slugs 214D are inserted uniformly, almost to the inner edge of the bars 212D. The disc may be removed and another disc having a greater diameter may be placed over the top of the slugs 214D and the disc is tapped in the direction of the bars 212D to seat the slugs towards, or against, the bars 210D. The same procedure may be used to insert and seat the slugs 214D on the opposite end of the rotor assembly 200D. The discs 210D at each end may be used in a conventional
press to press the discs towards one another, further seating the slugs 214D against the stack of discs 210D.

[0275] In one embodiment, the slugs 214D, like the bars 212D, are made primarily of copper. A plating or coating of a brazing material is made to either the slugs 214D, the ends of bars 212D, or both. In one embodiment, the brazing material is pure silver. The plating or coating will cause the bars 212D and slugs 214D to braze to one another when the two are sufficiently heated. In one embodiment, the bars 212D are made of copper and the slugs 214D are made of copper, plated with pure silver. One advantage of this method and rotor is that the slugs 214D and the bars 212D can be extremely tight-fitting; because the slugs can be inserted fewer than all at the same time (e.g., one at a time), the full force of insertion can be devoted to the fewer than all slugs being inserted, whereas a cap piece with fins requires all of the fins to be inserted simultaneously. Because all of the fins are inserted simultaneously, the force of insertion delivered to each one is less than all of the force, and the tolerances are made larger to accommodate the lack of available force of insertion.

[0276] In contrast to conventional rotors using cap pieces, the slugs 214D are not mechanically or electrically attached to one another before they are pushed into the spaces between the bars. The slugs 214D may, however, be mechanically or electrically attached, however, doing so would have little functional value. Thus, mechanical or electrical attachment of the slugs 214D to one another via some mechanism other than a conventional cap plate and that would enable the slugs 214D to be pushed axially into the rotor assembly 200D is permitted, but not required.

[0277] An optionally thermally-expandable force is applied 116D to the ends of the slugs 214D towards the center of the rotor assembly 200D to press the ends of the slugs 214D against the outer faces of the nearest disc 210D at each end of the stack. To apply such a force, in one embodiment, a green chromate coated stainless steel plate 222D is slipped over bolt 220D running along the axis of the stack of discs 210D and extending beyond the tips of the slugs 214D and bars 212D. The green chromate coating may be replaced with any coating that will help prevent the piece coated from brazing to the slugs 214D, bars 212D or any other portion of the rotor assembly 200D and need not actually be a green color. A nut 224D is tightened over the plate 222D using the bolt 220D. The plate 222D is used to distribute the force across the edges of the slugs 214D and bars 212D. A spring (not shown) is optionally placed between the plate 222D and the nut 220D at each end to allow for thermal expansion of rotor assembly 200D, though other means of doing so, such as by using a bolt 220D with an approximately equal or slightly lower coefficient of thermal expansion than the remaining portion of rotor assembly 200D may be used. This same arrangement is used on the other end of the rotor assembly 200D. The force is thus axially applied from the ends of the rotor assembly 200D towards its center.

[0278] An optionally thermally-expandable force is applied 118D radially, from outside the slugs 214D towards both 220D. The force may be applied in such a manner that it is present before and during the heating of the slugs 214D or it may be applied in a manner that causes it to be present when the slugs are heated, but not before, or the force may be very light before the slugs are heated but may increase as the slugs are heated if the application of the force is via one or more components that have a lower coefficient of thermal expansion than the remainder of assembly 200D. The force is applied in a manner that allows for it to be removed at a later time.

[0279] In one embodiment, the force is applied by the use of a removable collet 232D made of green-coated stainless steel, and a collar 230D at either end of the rotor assembly 200D. The collet 232D, with the collar 230D slipped over it, is slipped over the slugs 214D and the ends of the bars, and screws are inserted into holes 240D and tightened with bolts. The collar 230D is tightened together with the collet 232D, using one or more bolts and nuts through holes such as hole 236D and hole 238D. The collar 230D and collet 232D are shaped in such a manner that causes them, when tightened in this manner, to compress the slugs 214D towards bolt 220D. The collet 232D and collar 230D distribute the force of the tightening inward towards bolt 220D without adding torque to pull the slugs 214D or bars 212D out of position. Alternative solutions such as clamps could distribute the force inwards towards bolt 220D but could torque the slugs 214D or bars 212D in a circular fashion, which would provide a less-tight connection between one of the faces of slugs 214D and bars 212D. The compression used has the effect of forcing both faces of the slugs 214D against the faces of the bars 212D to tighten them during the brazing process described below, for a higher conductivity between their faces.

[0280] In one embodiment, the collet 232D contains fins such as fin 234D that have a wedge shape. That is, the part of the fins 234D contacting the collar 230D get thicker between the face that faces the slugs 214D and the opposite face at the base of the fins 234D as the screws tightening the collar 230D are tightened. The effect is to provide a "radially wedging" effect that provides the radial force. A radially wedging effect is the application of a radial force caused by a wedge shaped piece sliding over another piece or being slid over by another piece. This radial force is centrally-directed, that is directed inward towards the axis of bolt 220D.

[0281] In one embodiment, the bolts used to tighten the collar 230D and collet 232D are tightened against a spring to allow the collar 230D to expand slightly in response to the thermal expansion of the bars 212D and slugs 214D. Other means of accommodating thermal expansion may be used.

[0282] In one embodiment, instead of a collar/collet arrangement as described above, the force applied to the slugs 214D to tighten them against the bars 212D consists of one or more molybdenum alloy wires 250D (shown on FIG. 29D in white) wrapped around the outer edges of the slugs 214D. In one embodiment, four wires 250D are used, but other embodiments may use other numbers of wires 250D. The two ends of each molybdenum wire 250D are twist tied to one another, and the ends of the wires 250D may be cut off from the twisted portion. The one or more wires provide the force, and the molybdenum alloy provides for a limited amount of thermal expansion. As noted above, the force need not be particularly strong or exist at all until the assembly is heated. For example, the wires 250D may be only relatively loosely tied around the slugs 214D, providing little force until the slugs 214D are heated, although in other embodiments, the wires 250D apply force both before and during the heating process.

[0283] The rotor assembly 200D is then heated 120D in a furnace sufficiently to cause the slugs 214D to braze to the bars 212D. In one embodiment, the rotor assembly 200D is furnace-brazed in an atmosphere of 5% Hydrogen/95% Nitrogen (5% H₂/95% N₂) with a dew point at or above 25
degrees C. The 5% H₂ atmosphere provides a reducing environment that acts as flux to assure complete alloying of the copper and silver throughout the braze joints.

[0284] It can be helpful to ensure that the hydrogen percentage of the furnace-brazing atmosphere not exceed 5% H₂ and the dew point be at or above 25 degrees C. Atmospheres with higher percentages of H₂ and the dew points lower than 25 degrees C. may attack the surface insulation of the laminations on the discs 210D, which can significantly lower the surface insulation resistance increasing inter-laminar eddy current losses. Temperature may be measured at the point of the wires in the embodiment in which wires are used, or elsewhere in other embodiments.

[0285] The various forces applied as described above maintain the relative placement of the various components described above to maintain tight physical and electrical connections among them, while allowing for a limited amount of thermal expansion. If thermal expansion is not accommodated, the forces can cause the assembly to become misshapen in unpredictable ways. However, it can be helpful to have materials with a lower coefficient of thermal expansion used to apply forces, so as to tighten the assembly 200D as it is heated.

[0286] The rotor is then cooled 122D using a conventional annealing schedule. The collars 232D and collars 230D, bolts, including bolt 220D, springs and plates 222D used to apply the forces described above may be removed 124D. Step 124D may include milling, sanding or otherwise shaping the new raised slugs 214D and bars 212D, in order to shape them into a cylindrical shape. The milling can also remove the wires, which may braze onto the slugs 214D and bars 212D.

[0287] One or more Beryllium-copper bands are heated 126D to expand them and slipped 128D over the slugs 214D so that as the bands cool, they will exert a radial force towards the axis of the rotor. The assembly is allowed to reach room temperature 136D, compressing the one or more bands around the slugs 214D. If desired, before the bands are slipped over the rotor assembly 200D, as part of step 132D, at least the ends of the rotor assembly 200D are shrunk by chilling them. As the temperatures of the bands and the rotor approach equilibrium in step 136D, the bands are set onto the rotor assembly 200D with an interference fit.

[0288] The rotor assembly 200D can then be finished using conventional rotor components, and the finished rotor used to build 138D a conventional electric motor using conventional techniques. The electric motor including the rotor assembly 200D can be used to build 140D conventional products such as partially- or fully-electrically powered vehicles, such as electric or hybrid-electric automobiles, rockets, and the like.

[0289] FIG. 32 schematically illustrates a thermal management system 100E in accordance with a preferred embodiment of the invention. System 100E is comprised of four subsystems; power train cooling subsystem 101E, refrigeration subsystem 103E, battery cooling subsystem 105E, and heating, ventilation and cooling (HVAC) subsystem 107E. Each subsystem will now be described in detail.

[0290] Subsystem 101E is comprised of a continuous power train cooling loop 109E which is used to cool drive motor 111E, the vehicle’s principal traction motor. Preferably cooling loop 109E is also used to cool various system electronic components 113E (e.g., the power electronics module for motor 109E). System electronics 113E are preferably mounted to a cold plate 115E which is used to transfer the heat away from the electronics and into the liquid coolant (i.e., the heat transfer medium) contained in the cooling loop. Cooling loop 109E also includes a pump 117E to circulate the coolant through the cooling loop, a radiator 119E for discharging the heat to the ambient atmosphere, and a coolant reservoir 121E. Preferably the system also includes a fan 123E for forcing air through radiator 119E when insufficient air is passing through the radiator to achieve the desired level of cooling, for example when the vehicle is not moving.

[0291] Refrigeration subsystem 103E is comprised of a compressor 125E, condenser 127E, fan 129E, thermostatic expansion valve 131E, heat exchanger 133E and dryer/separator 135E. Compressor 125E compresses the low temperature refrigerant vapor in the system into a high temperature vapor. The refrigerant vapor then dissipated a portion of the captured heat when it passes through condenser 127E, thereby leading to a phase change from vapor to liquid, the liquid remaining at a high temperature and pressure. Preferably the performance of condenser 127E is enhanced by using a blower fan 129E. The liquid phase refrigerant then passes through thermal expansion valve 131E which lowers both the temperature and pressure of the refrigerant as well as controlling the flow rate of refrigerant into heat exchanger 133E. Heat exchanger 133E provides a simple means for transferring heat between the refrigerant contained in subsystem 103E and the coolants contained in the other subsystems. After being heated in heat exchanger 133E, the refrigerant is separated into the liquid and vapor phases by dryer/separator 135E, thus insuring that only vapor passes through compressor 125E. It should be appreciated that although refrigeration subsystem 103E is preferred, the invention can utilize other refrigeration subsystems as long as the used refrigeration subsystem includes a heat exchanger which can be used cooperatively with the other thermal subsystems of the vehicle as described herein.

[0292] Battery cooling subsystem 105E includes the energy storage system 137E (ESS) coupled to a coolant loop 139E containing the coolant (i.e., a heat transfer medium). In a typical electric vehicle, ESS 137E is comprised of a plurality of batteries. The coolant is pumped through ESS 137E, typically via a heat transfer plate (not shown) coupled to ESS 137E, by circulation pump 141E. During normal operation, the coolant contained in loop 139E is cooled via heat transfer with the refrigerant in heat exchanger 133E. Additionally, in a preferred embodiment of the invention, cooling loop 109E is also thermally coupled to a heater 143E (e.g., a PTC heater), thus insuring that the temperature of ESS 137E can be maintained within its preferred operating range regardless of the ambient temperature. Subsystem 105E also includes a coolant reservoir 145E.

[0293] Heating, ventilation and cooling (HVAC) subsystem 107E provides temperature control for the vehicle’s passenger cabin. It includes a fan 147E which is used to circulate air throughout the cabin on demand, regardless of whether the air is heated, cooled, or simply fresh air from outside the vehicle. To provide cool air, circulating pump 149E circulates coolant contained within coolant loop 151E through radiator 153E, the coolant contained in loop 151E being cooled by heat transfer with the refrigerant in heat exchanger 133E. To provide warm air during normal vehicle operation, subsystem 107E is coupled to subsystem 101E via flow control valves 155E, 157E, and 159E, thus allowing the coolant heated by subsystem 101E to flow through radiator 153E. Additionally, in a preferred embodiment of the invention, a heater 161E (e.g., a PTC heater) is integrated within
radiator 153E, thus allowing cabin heating prior to that achievable by subsystem 101E alone.

[0294] It will be appreciated that there are numerous ways of controlling the amount of cooling supplied by refrigeration subsystem 103E to the other subsystems. One approach is through the use of valves, for example a valve within coolant loop 139E can be used to control the flow of coolant through the battery cooling subsystem 105E and thus the level of cooling achieved via heat exchanger 133E. Similarly a valve within coolant loop 151E can be used to control the flow of coolant through HVAC subsystem 107E and thus the level of cooling achieved via heat exchanger 133E. Alternately, as both the battery cooling subsystem 105E and the HVAC subsystem 107E place a thermal load on heat exchanger 133E of refrigeration subsystem 103E, by simply varying the speed of the two coolant circulation pumps within these two subsystems, i.e., coolant pumps 141E and 149E, respectively, the level of cooling achieved by the two subsystems is continuously variable, thereby avoiding the necessity of valves within the coolant loops.

[0295] As will be understood by those familiar with the art, the present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. Accordingly, the disclosures and descriptions herein are intended to be illustrative, but not limiting, of the scope of the invention which is set forth in the following claims.

[0296] FIG. 33 schematically illustrates the primary components of the rotor assembly cooling system of the invention. Rotor assembly 100F includes a rotor 101F fixed to a rotor drive shaft 103F. Drive shaft 103F is hollow and closed at end 105F and open at end 107F. Although not a requirement of the invention, preferably shaft 103F is hollow over the majority of its length, including that portion of the shaft in contact with rotor 101F, thereby insuring efficient cooling of the rotor assembly. A hollow coolant feed tube 109F is rigidly attached to shaft 103F with at least one, and preferably a plurality of support members 111F.

[0297] During operation, coolant is pumped into end 113F of feed tube 109F. The coolant flows through the length of feed tube 109F until it is redirected by the inside surface of closed end 105F of shaft 103F. The coolant then flows back along direction 115F towards the inlet, passing within the coolant flow region between the outer surface of feed tube 109F and the inside surface of shaft 103F thereby cooling the drive shaft and the attached rotor.

[0298] As both shaft 103F and feed tube 109F rotate, the assembly requires at least one coolant seal 117F to seal rotating shaft 103F, and at least a second coolant seal 119F to seal rotating feed tube 109F. It will be appreciated that seal 117F is more critical than seal 119F as coolant leaked from seal 119F will simply re-enter the coolant reservoir.

[0299] Support members 111F can take any of a variety of forms, a few of which are shown in the cross-sectional views of FIG. 34-38. The support member shown in FIG. 34 is comprised of a plurality of spokes 201F that rigidly couple feed tube 109F to shaft 103F. The support member shown in FIG. 35 also includes a plurality of spokes 301F, however in this support member the spokes are coupled to a pair of concentric rings 303F and 305F which are rigidly coupled to feed tube 109F and shaft 103F, respectively. Although the members shown in FIGS. 34 and 35 both utilize spokes, the member shown in FIG. 35 is generally easier to fabricate than the member shown in FIG. 34. It will be appreciated that a fewer or a greater number of spokes can be used with either of the support members shown in FIGS. 34 and 35.

[0300] FIG. 36 shows another alternate embodiment of the support member. In particular, member 401F is a ring-shaped member which includes a plurality of perforations 403F that provide the necessary coolant path. Member 401F can utilize fewer or greater number of perforations, different size perforations or perforations of varying size within a single member.

[0301] FIG. 37 shows another alternate embodiment of the support member. As shown, member 501F includes a plurality of slotted openings 503F. Preferably openings 503F are angled, thus allowing members 501F to provide an additional means for pumping the coolant as it passes through the region between feed tube 109F and shaft 103F. Although member 501F is shown with slanted slots, it should be understood that other shapes can be used in the slanted openings, for example slanted perforations. Additionally, member 501F can utilize fewer or greater numbers of openings than shown.

[0302] In addition to using a plurality of support members to couple feed tube 109F to shaft 103F, in at least one embodiment of the invention a continuous support member 601F is used, as illustrated in FIG. 38. As shown, member 601F is comprised of a continuous support strut which helically wraps around feed tube 109F and couples it to shaft 103F. Due to the helical shape of member 601F, coolant is actively pumped in the region separating feed tube 109F from shaft 103F, thus insuring continuous coolant flow to the rotor assembly.

[0303] In order to improve coolant flow when the coolant undergoes the directional change at the end of feed tube 109F, adjacent to end 105F of feed tube 103F, preferably the inside surface 701F of the end of feed tube 103F is shaped, for example as illustrated in FIG. 39. Shaping surface 701F promotes coolant flow and reduces flow stagnation. It will be appreciated that shaping surface 701F aids coolant flow regardless of the configuration used for the support member.

[0304] It should be understood that an electric motor utilizing the rotor assembly cooling system of the present invention is not limited to a specific implementation. FIG. 40 conceptually illustrates the basic elements of an electric motor utilizing the present invention. It will be appreciated that FIG. 40, as with the other figures included herein, is not drawn to scale.

[0305] The other elements of electric motor 800F are the same as in a conventional electric motor. For example, motor 800F includes a stator 801F, drive shaft bearings 803F and motor case 805F. The rotor cooling assembly, in addition to the other elements previously described in detail, also includes a coolant reservoir 807F within a housing 809F and a coolant pump 811F. In at least one embodiment, housing 809F also contains the transmission thus allowing the coolant to also be used to cool and lubricate the transmission. In at least one alternate embodiment, housing 809F is a separate housing used only for coolant containment and circulation, thus requiring the other end of the drive shaft to be coupled to the power train of the vehicle. It will be appreciated that the rotor cooling assembly of the invention can be used in conjunction with other cooling systems, for example a coolant system integrated into the motor housing.

[0306] As will be understood by those familiar with the art, the present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. Accordingly, the disclosures and descrip-
tions herein are intended to be illustrative, but not limiting, of the scope of the invention which is set forth in the following claims.

[0307] Referring to the drawings, an energy storage system 10G and methodology for balancing batteries within the energy storage system 10G is shown. The energy storage system (ESS) or battery pack 10G is generally comprised of a predetermined number of battery modules or sheets 12G, a main control and logic PCB 14G, and a 12 volt power supply 16G. In one embodiment contemplated the energy storage system 10G will have eleven battery modules or sheets 12G which is capable of producing approximately 375 volts DC. This nominal voltage will operate an electric vehicle that will be capable of traveling many miles without recharging and is capable of delivering enough power and acceleration to compare favorably with internal combustion engines. In one contemplated embodiment the battery pack 10G will be capable of storing enough energy such that the electric vehicle can travel approximately 200 miles without recharging. However, it should be noted that it is also contemplated to have an electric vehicle based on the present invention that can travel well over 200 miles without recharging. It is also contemplated in one embodiment that the electric vehicle using the battery pack 10G of the present invention will be capable of accelerating from zero to 60 miles per hour in approximately four seconds. No other electric car known has produced this type of acceleration and mileage range without recharging.

[0308] The present invention uses batteries 18G made of lithium ion cells. In particular, one embodiment uses commodity 18,650 form factor lithium ion cells for the electric vehicle. The batteries 18G in the present invention store the chemical energy equivalent of approximately two gallons of gasoline. The battery pack 10G operates at a nominal 375 volts and delivers approximately up to 240 horsepower to the motor. The energy and power capabilities of the battery pack 10G allow for the battery pack 10G design and architecture to have many features that ensure the safety of the vehicle and its occupants during the use of the electric vehicle. It should be noted that the lithium ion cells 18G are rechargeable such that after recharging, the batteries 18G will be able to provide traction power for the vehicle based upon a fully recharged and capable battery. The battery pack or energy storage system 10G in one embodiment comprises 6,851 individual lithium ion 18,650 cells that will allow for it to achieve the drive power and range necessary for the vehicle. These cells 18G are electrically connected in parallel groups of 69 cells where each of these groups of 69 cells constitutes an electric module called a brick 20G.

[0309] The bricks 20G are then connected in series within individual battery modules 12G in the energy storage system 10G called sheets 12G. Each sheet or battery module 12G is a single mechanical assembly and consists of nine bricks 20G electrically connected in series. It should be noted that it is contemplated that the sheets or battery modules 12G will be the smallest replaceable unit within the battery pack 10G. Each sheet or battery module 12G generally has a nominal voltage of approximately 35 volts DC. Furthermore, each of these sheets 12G contains a mechanical mounting system, battery monitoring hardware electronics, a cooling system, as well as various safety systems to ensure proper protection for the vehicle and occupants of such vehicle. In the embodiment contemplated eleven sheets 12G will be used in total to bring approximately 375 nominal volts DC to the ESS 10G for use in the electric car. Each of these sheets are rigidly mounted in an ESS enclosure 22G and electrically connected to one another in series. This series connection will create the nominal voltage of approximately 375 volts DC as described above. It should be noted that the ESS 10G contemplated and shown in the present invention has a nominal voltage of approximately 375 volts, however that voltage can be adjusted by either increasing or decreasing the number of sheets and/or boards within the ESS or battery pack 10G. Furthermore, each sheet 12G will also contain a fuse that is electrically in series. The ESS 10G will also generally include two normally open contactors 24G that are controlled by a watchdog computer, i.e., BSM or battery safety monitor 26G, that is also capable of shutting off high voltage to the rest of the vehicle in the case of a fault within the battery pack 10G. The ESS 10G also includes an auxiliary power system or APS 28G, a DC to DC converter, which provides 12 volt power to the rest of the vehicle. It should be noted that the entire system is contained inside an enclosure 22G which prevents access to any high voltage leads from occupants or users of the vehicle. In one embodiment contemplated the enclosure 22G is made of an aluminum material, however any other non conductive material may be used depending on the design requirements of the vehicle. The system 10G also includes a plurality of other components such as electrical hardware to monitor the battery 32G, a plurality of sensors to monitor the environment, a cooling system 30G and other safety features intended to create a safe environment for the occupants and users of the electric vehicle. It should be noted that when the contactors 24G within the ESS enclosure 22G are not energized by the battery safety monitor 26G and are in their normal or open state, there is no external high voltage access available outside of the ESS enclosure 22G in the electric vehicle.

[0310] The ESS 10G includes battery monitoring boards (BMB) 34G. A battery monitoring board 34G is associated with each sheet 12G of the battery pack 10G. The battery monitoring board 34G monitors the voltage levels and other parameters of all of the bricks 20G within its sheet 12G. As described above, nine bricks 20G are electrically connected in series within each sheet 12G. However, it should be noted that any other number of bricks 20G or sheets 12G may be used for the ESS or battery pack 10G of the present invention. The battery monitoring board 34G also is capable of connecting a small load to an individual brick 20G within its sheet 12G to bleed the brick voltage of that specific brick 20G to a lower level. It should further be noted that the battery monitoring boards 34G are networked to each other using a controller area network (CAN) bus. In an effort to more efficiently use the power provided by the ESS or battery pack 10G it is desirable to have all of the voltage levels of all of the bricks 20G within the battery pack 10G at the same voltage level. In the embodiment contemplated it is desirable to have each of the voltage levels of all bricks 20G within the battery pack 10G within a predetermined voltage delta (∆V). In one embodiment contemplated the voltage delta is approximately 20 millivolts. However, the voltage delta may be within the range of one millivolt up to many volts depending on the design requirements for the battery pack 10G and the electric vehicle. There is a desirability to have the voltage levels of all bricks 20G match as closely as possible to one another to increase efficiency of the batteries and range of the electric vehicle, this is generally accomplished by balancing of the batteries.
[0311] The present invention includes a self-balancing methodology or algorithm 40G for use in the battery pack or ESS 10G of the present invention. It should be noted that the methodology 40G can be used on any battery or battery system or pack not just those in vehicles. A general flowchart is shown in FIG. 46 for such a self-balancing methodology 40G. As shown in FIG. 46, the methodology starts in box 42G where each of the battery monitoring boards 34G will periodically sample the voltage level of all of its bricks 20G at a predetermined interval. Then in box 44G the battery monitoring board 34G will determine the lowest brick voltage within its sheet 12G. The methodology then enters block 46G and sets or initializes each battery monitoring board 34G with a target balance voltage (TBV) value. Initially this target balance voltage value is set to the lowest brick voltage within the individual sheet 12G to which the battery monitoring board 34G is associated therewith. Therefore, each battery monitoring board 34G will take the voltage of each of the bricks 20G within its sheet or battery module 12G and determine which is the lowest brick voltage within its sheet 12G and use that lowest brick voltage as its initial target balance voltage value within the methodology. The methodology then in block 48G will send that voltage via the CAN bus to all other battery monitoring boards 34G. This announcement of the voltage level of the lowest brick by one of the battery monitoring boards 34G, via the CAN bus, will allow all of the other battery monitoring boards 34G in this example the other ten, to receive such announcement of the voltage level of the lowest brick in this other battery monitoring board 34G. In box 50G upon receiving the announcement of the voltage level of the lowest brick in any of the other sheets 12G the receiving battery monitoring board 34G will compare the announced lowest brick voltage level to their own target balance voltage value stored within their sheet system. If the announced low brick voltage is lower than the target balance voltage then the target balance voltage will be replaced, by the methodology in box 52G, within the battery monitoring board 34G that received and processed the announced lowest brick voltage. This will ensure that all of the battery monitoring boards 34G will have the lowest brick voltage stored as the target balance voltage at all times across the entire battery pack 10G. If the announced low brick voltage is not lower than the battery monitoring boards 34G own stored target balance voltage then the stored target balance voltage will be kept as the low brick voltage within the system. The methodology then in box 54G will sample the voltages of all the bricks 20G. The methodology next will enter box 56G and compare the target balance voltage of each battery monitoring board 34G to the sampled voltages of the bricks 20G within the sheet 12G of each battery monitoring board 34G. The battery monitoring boards 34G will compare the sampled voltage of all of their bricks 20G to determine if that voltage is higher than the target balance voltage. If the target balance voltage is less than the sampled voltage then the methodology will determine if the sample voltage is outside of the voltage delta as described above. If the sampled voltage is outside the voltage delta the methodology has the battery monitoring board 34G issue a command to bleed the brick 20G having the higher voltage to a level where the voltage of the brick 20G matches or is within the voltage delta of the target balance voltage. The bleeding of the brick 20G occurs by applying a small load to the brick 20G to bleed the charge and ensure balancing between the bricks 20G of the battery pack or ESS 10G. It should be noted that after all of the bricks 20G are bled to the same general relative voltage value the methodology will return and continue sampling of the voltages across all boards as described above.

[0312] It should also be noted that safeguards are built into the methodology 40G to ensure proper use of the balancing algorithm within the ESS 10G. One of the safeguards will prevent a bricks 20G from being completely discharged. To protect against complete discharge the methodology will query whether the sampled voltage or target balance voltage is less than a fixed minimum voltage value. It should be noted that the minimum fixed voltage value can be any voltage between zero and 375 volts depending on the design requirements of the ESS system of the present invention. If the brick voltage being bled is equal to the fixed minimum voltage value the bleeding of the brick 20G will be stopped via commands from the balance monitoring board 34G. This will ensure that the brick 20G and battery cells 18G associated therewith are never completely discharged.

[0313] Furthermore, another safeguard that the methodology uses will allow it to monitor and recover from an anomalous announced low brick voltage or a low brick voltage announced by a battery monitoring board 34G that is no longer in the ESS and/or connected to the CAN bus. To prevent such occurrences each of the battery monitoring boards 34G will periodically replace its own target balance voltage with the lowest voltage from its own bricks 20G as the methodology shows in box 60G. This periodic replacement will occur at predetermined intervals and when an announced brick voltage that is less than or equal to the battery monitoring boards target balance voltage has not been received for a predetermined time interval. In one contemplated embodiment this time interval will be approximately 240 seconds. However, any other time interval may be used depending on the design requirements of the ESS 10G. It should be noted that the time intervals should be greater than the voltage announcement interval. In one contemplated embodiment the battery monitoring board announces its low brick voltage approximately every 120 seconds. However, it should be noted that any other time interval can be used depending on the design requirements for the ESS 10G. It should further be noted that in order to prevent all of the battery monitoring boards 34G from announcing their low brick voltages simultaneously the first announcement after booting of the system 10G is delayed by a predetermined amount of time based upon the battery monitoring boards 34G unique CAN identification or ID.

[0314] It should further be noted that voltage measurements may not be valid while the ESS 10G is being charged or discharged at high current during operation of the vehicle. As such balancing of the bricks 20G and batteries may be disabled by use of commands from an external microprocessor during such charging and discharging operations. If the voltage measurements are not valid the balancing becomes ineffective and at such time the external microprocessor will disable the balancing algorithm from operating. After the charging or discharging at high current is complete the external microprocessor will enable the balancing algorithm and methodology to continue. However, the system also will prevent the balancing methodology and algorithm from being permanently disabled by having the balancing algorithm only disabled for a specified time period that can be anywhere from a few milliseconds to many minutes depending on the charging or discharging at high currents occurring in the ESS 10G. It should further be noted that the self-balancing methodology
of the battery pack or ESS 10G will allow for balancing of the batteries to begin from the moment a battery monitoring board 34G is attached to a sheet 12G. Furthermore, if sheets 12G are connected or disconnected from each other balancing will automatically occur between the sheets 12G via announcement of the lowest brick voltage via the CAN within the vehicle electrical architecture.

[0315] The methodology also may include an alternate embodiment or implementation that will operate in the same general manner as the methodology described above. The alternate methodology, via the battery monitoring boards 34G, will first periodically sample the voltage level of all of its bricks 20G at a predetermined interval. The alternate methodology will next in block 44G compute, via the battery monitoring board 34G the highest brick voltage within its sheet 12G. Next the alternate methodology in block 46G will initialize the target balance voltage with the highest brick voltage found within its sheet 12G. Next in block 48G the battery monitoring board 34G will periodically at predetermined intervals send or announce its highest brick voltage. This announced highest brick voltage will be sent to all other battery monitoring boards 34G, via the CAN bus, within the entire battery pack 10G. Then in block 50G all of the other battery monitoring boards 34G will receive the announced highest target brick voltage from the sheet 12G of the battery monitoring board 34G which announced such voltage. Then the battery monitoring board 34G that receives such highest brick voltage will compare such level to their own target balance voltage value stored within their system and determine if the highest brick voltage just received is greater than the presently stored target balance voltage. In block 52G if the announced and received highest brick voltage is greater than the stored target balance voltage, the received target brick voltage will be used to replace the target balance voltage within the battery monitoring board 34G. This alternate methodology will then enter block 54G and sample the voltage of all of the bricks via the battery monitoring board 34G associated therewith. Next in block 56G the alternate methodology will compare the target balance voltage with the sampled brick voltages in each battery monitoring board 34G. The sample voltages will be compared to the target balance voltage to determine if the sampled voltage, of block 54G, is less than the target balance voltage stored in the battery monitoring board 34G. If the sample voltage is less than the target balance voltage and the sample voltage is outside of the voltage delta, as described above, the alternate methodology will adjust by raising the voltage or charging the brick 20G having the sampled voltage such that the voltage will be raised to that of the target balance voltage which is the highest brick voltage in the battery pack 10G. It should be noted that the second method for the highest brick voltage also includes safe guards to ensure that a maximum voltage for each brick 20G is not crossed by overcharging the brick 20G over the target balance voltage just as that described above for the other implementation of the lowest brick voltage target balance voltage. The alternate methodology will also include a timeout portion for the algorithm to periodically replace the target balance voltage if predetermined parameters are met and a predetermined amount of time passes with the TBV not being changed.

[0316] It should be noted that the alternate methodology that raises the voltage of the lowest brick up to the level of the highest brick is contemplated to be implemented by only using energy from other bricks in the sheet 12G or battery pack 10G and/or may be from other residual energy collected during operation of the vehicle. It should be noted that the alternate methodology of raising the voltage of the lowest brick up to the level of the highest brick may lead to a more efficient methodology and ESS 10G. This efficiency will be achieved through the use of energy being shifted and moved between bricks 20G and not bled as described in the methodology described above. Therefore, the redistribution of the energy among the bricks 20G will lead to a more efficient system and increased range of the vehicle. It should be noted that the sampling of voltages occur at intervals that will allow for a constant movement of the target balance voltage for the highest brick voltage of the battery pack 10G and/or sheet 12G to be constantly adjusted in either an upward or downward direction depending on the energy shift between battery bricks 20G during operation of the alternate methodology. Thus, if the lowest brick voltage is charged to the currently stored highest target balance voltage, such charging of the lowest brick voltage will shift energy from other bricks 20G within the sheet 12G or battery pack 10G thus generally lowering the highest target balance voltage a predetermined amount. The constantly changing highest target balance voltage will in effect shift the charge throughout the battery pack 10G such that the batteries remain in balance thus increasing efficiency and range of the electric vehicle. It should be noted that this second methodology may be used in any known vehicle and in any known system such as but not limited any system that uses batteries or any other known electrical system and is not limited to use in vehicles. Therefore, either the highest target balance voltage or lowest target balance voltage methodology as described herein may be used for any known system that uses batteries or battery packs to provide power to such system or the like.

[0317] Referring to the drawings, an electric vehicle communication interface 10H is disclosed. The electric vehicle communication interface 10H is for use in any type of vehicle including an automobile, boat, train, plane, or any other transportation vehicle. However, it is specifically designed for use in an all electric vehicle 12H. The all electric vehicle 12H will operate completely on battery power for all propulsion and other automotive related needs. The electric vehicle 12H of the present invention uses a battery pack made of sheets of cells of lithium ion batteries arranged in a predetermined pattern. This battery pack will allow for propulsion of the electric vehicle 12H some distance before recharge is necessary. It should also be noted that the electric vehicle communication interface 10H of the present invention may be used in any other type of automotive vehicle, such as internal combustion, hydrogen cell vehicle, hybrid vehicle, alternate fuel type vehicle, or any other type of propulsion system known for a vehicle. It should also be noted that the electric vehicle communication interface may be completely wireless or include hard wire portions for use in connecting components as described herein.

[0318] FIGS. 47 and 48 show the electric vehicle communication interface 10H according to one contemplated embodiment of the present invention. It should be noted that other contemplated embodiments for the connections necessary for the electric vehicle communication interface 10H may be possible. The electric vehicle communication interface 10H generally includes a communication device 14H arranged and installed within the electric vehicle 12H. The communication device 14H may be installed in any predetermined position within the electric vehicle 12H and may also
be incorporated into the computer controlling the vehicle internal network. However, the communication device 14H may also be a stand alone device depending on the device requirements and environment in which the electric vehicle 12H will be used. Generally, the communication device 14H is a communication chip which may use an 802.11 protocol, cellular or other standard protocol which are all well known in the art. In one specific embodiment a communication chip 14H developed by CircumNav Network may be used for the communication device 14H of the present invention. The electric vehicle 12H uses a communication chip 14H that is capable of communicating via any known protocol such as TCP/IP, GPRS, or any other standard protocol. The communication chip 14H allows for communication with a network 16H that may be cellular, internet, satellite or any other type of network or with a wired or wireless access point 28H. After the initial communication with network 16H the methodology then sends a communication from the network 16H to a second network 18H or to the user or driver 20H of the vehicle, or to a utility company or the manufacturer of the electric vehicle communication hub or server 22H. The second network 18H may include a manufacturer server or utility company server or any other known type of network while the first network 16H may include any cell tower, computer network, satellite system or hard line such as a phone network or power line network. The user 20H will be capable of communicating with either the first network 16H, the second network 18H, or directly with the vehicle 12H via any user interface device 24H. Contemplated user interface devices 24H may include but are not limited to mobile devices, such as cell phones, PDA’s, handheld devices, desktop computers, laptop computers or any other communication device that is capable of producing email, IM, or any other communication device that is well known in the art. Some of these communications between the user interface devices 24H and either the first and second network 16H, 18H or the vehicle 12H may be performed via the code division multiple access standards (CDMA), the time division multiple access standards (TDMA), the global system for mobile communication standards (GSM), 802.11, Bluetooth, ZigBee, powerline communications including but not limited to HomePlug or Lonworks, a proprietary or standard communications protocol overlaid on existing charging communications equipment, a standard protocol such as CAN implemented on a custom physical layer, or any other standard protocol that is known in both wireless and hardwired configurations, for communication between any of the known user interface devices 24H and the first and second network 16H, 18H or the electric vehicle 12H directly. 

[0319] If the 802.11 standard is chosen for use in the electric vehicle 12H, the user 20H of the vehicle may then need to install and use a wireless router or any other known wireless access point 28 to enable the router to accept login from the electric vehicle 12H to allow for communication between the user interface device 24H and the electric vehicle communication chip 14H which operates on the 802.11 standard. It should be noted that with the other standards or protocols contemplated for use, other specific needs such as wireless router, hardwired connections, or the like may be needed and are all contemplated for use if necessary depending on the design requirement of the electric vehicle communication interface 10H as used in the electric vehicle 12H.

[0320] The use of the communication chip 14H as described above in the electric vehicle 12H may allow for communication to the first network 16H to allow for the vehicle 12H to contact the user 20H via the user interface device 24H by any known mobile device or desktop, laptop, etc., via either email, instant messaging or any other known communication protocol. Also, it should be noted that the user or driver 20H of the vehicle is also capable of communicating with the electric vehicle 12H from their portable device such as a cell phone, PDA, laptop, personal computer, server, any known text messaging device, or any other communication device either directly with the vehicle 12H or through the first and second networks 16H, 18H to the vehicle to program and send specific instructions to the electric vehicle 12H for controlling and monitoring the battery system 26H arranged within the electric vehicle 12H. This communication between the electric vehicle 12H and user 20H or user 20H and electric vehicle 12H enables a plurality of scenarios through which the communication will have specific functions with respect to the propulsion system and other internal components of the electric vehicle 12H. In one contemplated controlling methodology for the communication interface 10H, the user 20H may be capable of querying or monitoring the electric vehicle’s battery pack and cells 26H for its state of charge (SOC). This will allow the user 20H to determine if the battery 26H is capable of driving the distance the user 20H must travel, if the battery 26H has not been charged or if the battery 26H is charged to the level set by the user and capable of a maximum mileage trip based on the battery installed therein. Another contemplated methodology will have the electric vehicle 12H notifying the user or driver 20H that the battery 26H is fully charged and is ready for driving. Yet another methodology contemplated will have the vehicle 12H notifying the user or driver 20H that a problem occurred during charging of the battery 20H and that the maximum distance for travel for the electric vehicle 12H has been reduced or that the electric vehicle 12H needs immediate servicing and is not available for driving at the present time. Still yet another methodology contemplated for the electric vehicle communication interface 10H for the present invention will have the user or driver 20H of the electric vehicle requesting the electric vehicle 12H to initiate heating or cooling of the vehicle 12H along with initiate heating or cooling of the battery cells and associated battery pack 26H to prepare for driving of the electric vehicle 12H. This preparation may include adjusting the battery temperature based on the distance of the expected drive, the external temperature that the electric vehicle 12H will be used in, the weather in which the electric vehicle will be driven and/or any other parameters that effect the performance and durability of the battery 26H and hence the electric vehicle 12H in the driving environment. Still yet another methodology contemplated for use in the communication interface 10H of the present invention may have the user 20H capable of powering on and off in predetermined cycles and at predetermined times the charging of the battery 26H from a user interface device 24H. Furthermore, the user 20H may be capable of discharging the battery 26H into the electricity or electric grid of the locale in which the electric vehicle 12H is either charged or stored via a vehicle to grid application that will allow for communication between a local utility company server and the electric vehicle 12H, thus allowing for certain operations to be performed by the utility company and the user 20H on the electric vehicle 12H. Yet another use would be to alert the user or manufacturer that the battery 26H is falling below the minimum accepted storage levels (3.0V for example). Such dis-
charge of the battery 26H may allow the user to plug in the vehicle or recharge the battery 26H by other means to preserve the battery 26H.

[0321] The vehicle to electricity grid applications and methodology may allow for the user 20H to either pre-register or associate with a local utility company or energy provider which will allow for the utility company to control the timing of charging or discharging of the electric vehicle 12H. This will allow the utility company during periods of high power consumption to have the option of turning off the charging of the electric vehicle 12H to help reduce the load on the electric grid controlled by the utility company and to avoid the sometimes necessary rolling blackouts. This also may allow for charging the vehicle 12H during periods of low power consumption by having the utility company to turn off the charging of the electric vehicle 12H back on thus reducing the overall cost of operating the electric vehicle 12H by allowing for charging of the vehicle during periods of low power consumption which may result in lower kilowatts charges to the user of the electric vehicle 12H. It should be noted that the user 20H through the electric vehicle communication interface 10H and associated methodologies may be capable of having a preset operating command to automatically reject or accept such charging control or request for such from the utility company. This methodology would allow for the user 20H to override the utility company instruction of stopping charging because of high power consumption if the user 20H of the electric vehicle 12H needs the battery 26H charged at the current time in order to use the vehicle in the near future. It is contemplated that this type of mutual control between the utility company and the electric vehicle 12H may be executed via the internet using the 802.11 communication protocol or cell phone communication with the electric vehicle 12H by the user 20H or the utility company. It should also be noted that it is contemplated within this methodology that the utility company may also be capable of remotely querying and sampling the electric vehicles state of charge for the associated battery pack 26H and then send predetermined and specific instructions or requests to the electric vehicle and/or user to discharge electricity back into the grid via the vehicle to grid applications stored within the electric vehicle communication interface 10H. This will allow the user 20H to further reduce its cost by discharging electricity back into the electric grid of the utility company and hence receiving credits and the like.

[0322] The electric vehicle communication interface 10H also may include an in vehicle display 30H which may be any known display touch screen, screen, TV, tube or any other type of display device known. The dashboard display 30H may be arranged in any part of the vehicle 12H including but not limited to sun visors, heads up displays, anywhere in the instrument panel, anywhere in the seats, or any other position within the vehicle and it is even contemplated to have a touch screen on the outer surface of the vehicle. When the user or driver 20H of the electric vehicle 12H turns off the motor of the electric vehicle 12H, the user 20H may be prompted via the display device 30H in the vehicle 12H to choose or select one of a plurality of predetermined charging options for the electric vehicle battery pack 26H. It should be noted that the user 20H may also use a menu or voice controlled device that allows for selection of a next charge state at any time during use of the vehicle. In one contemplated embodiment there will be three separate charging options which will be displayed on the touch screen 30H display located in the vehicle’s interior compartment. These charging options may include a boost charge which in theory is a full charge to the battery 26H of the electric vehicle 12H. By selecting the boost charge, the user 20H will be able to have maximum driving range such that the next time the user drives the electric vehicle 12H they can travel the maximum distance capable from the electric vehicle, however the boost charge may affect the durability and battery life of the battery pack 26H in the electric vehicle 12H over time. The second charging option displayed to the user or driver 20H of the electric vehicle 12H will be the regular charge option. The regular charge option generally will deliver a constant current charge up to a predetermined set voltage. The predetermined set voltage will be determined based on the battery pack system 26H and the configuration of the battery pack therein. It should be noted that a taper charge will not be used during the regular charge, which will result in the battery 26H not being completely charged after the regular charge option is chosen by the user. However, the regular charge will benefit the driver/user 20H of the vehicle 12H by allowing a quicker charge of the battery 26H and prolong battery life of the battery pack 26H in the electric vehicle 12H. However, the driving range will be reduced by a predetermined amount when selecting the regular charge option. In one contemplated embodiment the driving range will be reduced by about 4 to 10%. However, the reductions may generally be anywhere from 2% to 30% depending on the design requirements and batteries therein. The third option for one contemplated embodiment for charging of the battery pack 26H of the electric vehicle 12H will be a storage charge. This will allow the user 20H of the vehicle that does not plan to use the vehicle on a regular basis to maximize the life of the battery pack 26H. Generally, the storage charge is approximately a 30 to 50% charge. However, it should be noted that a range of 10 to 70% charge may also be used depending on the design requirements and environment in which the electric vehicle will be used. The storage charge will allow for the maximum life and durability of the battery pack system 26H in the electric vehicle 12H.

[0323] It should also be noted that the charging options may also include within its methodology a follow up menu that will allow the user or driver 20H of the vehicle 12H the choice of setting one of the predetermined charging options as the default such that every time the user exits the vehicle and begins charging of the battery pack 20H within the electric vehicle 12H such setting will be automatically used for charging thereof. It should also be noted that the methodology of charging options as discussed above may also be added to a key/lock such that the options are capable of being chosen via a key/lock that comes with the electric vehicle 12H. Furthermore, the options may also be added to a cell phone connection or other mobile device to follow the network connections of the first and second network 161H, 181H as described above to allow for choosing of one the charging options and setting any default via any user interface device 24H.

[0324] The communication chip 14H using the GPRS, which is a general packet radio service protocol, 802.11 standard, TCP/JP or any other standard protocol may communicate with a vehicle management system 32H which is the onboard computer that monitors, controls and coordinates various systems in the electric vehicle 12H including the power electronics module 34H, the energy storage system 26H and the HVAC system along with the user interface 30H. The communication chip 14H may also communicate with the wireless access point 28H or the power electronics module 34H. The energy storage system 26H, which is controlled
by the vehicle management system 12|H| via a CAN BUS or any other known communication interface or path, includes the battery pack of the electric vehicle 12|H| which is used to provide the power necessary to propel the electric vehicle 12|H| without the need for an internal combustion engine. The power electronics module 34|H| which is also controlled by the vehicle management system 32|H|, will house a DC to AC inverter for a traction motor, a AC to DC rectifier for charging and the control PCB's for drive and charge of the electric vehicle energy storage system. The power electronics module 34|H| may also be in communication with an electric vehicle service equipment module 36|H| via power line communication, CAN BUS or any other known communication method, which also may be in communication with the display device 30|H| of the electric vehicle 12|H| for any messages to be communicated to the user of the vehicle via the display device 30|H| within the vehicle. These messages may include service, appointments, or other tips to improve the mileage and efficiency of the battery pack 26|H| within the electric vehicle 12|H|.

[0325] A further component of the methodology used in the electric vehicle communication interface 10|H| will allow for the electric vehicle 12|H| every time it comes into contact with the home network of the manufacturer of the electric vehicle 12|H| or any other open network that it will send a message automatically through the communication chip 14|H| and over any known protocol such as the 802.11 standard to the manufacturer's server 22|H| which may be networked to as described above. The server 22|H| may also be in communication with the display device 30|H|, the electric vehicle service equipment 36|H|, or the text message gateway 24|H|. The manufacturer may then be capable of forming a database 38|H| of the user data such that the data storage will be held separately on the manufacturer's server and will allow for cycle count, temperature, and other necessary data to be stored and evaluated or monitored to ensure efficient operation of the battery pack system and energy storage system within the electric vehicle 12|H|. The manufacturer's server 22|H| also may be capable of data analysis regarding the charging cycles of the battery, miles driven per charge, temperature of the batteries, and any other data that is relevant to the efficient operation of the electric vehicle 12|H|. Therefore, every time the electric vehicle 12|H| comes in contact with a home network or any other open network as described above it will automatically send, via a network, data to the manufacturer's server 22|H| from the vehicle 12|H|, battery pack and energy storage system 26|H|. It should be noted that the communication protocol methodology will give the user or driver 12|H| the option of disabling the automatic messaging to the manufacturer's server 22|H| via the vehicle display touch screen or via programming by a user interface device 24|H| on the internet or the like. It is also contemplated that upon initial programming of the vehicle 12|H| the user 22|H| may be able to set a default for either enabling or disabling the automatic message function. It should also be noted that it is contemplated that the methodology will allow the user or driver of the vehicle to access this data from the manufacturer's server 22|H| via a portable hand held device or personal computer if necessary. It should also be noted that the manufacturer may use this data to broadcast specific messages to the user or driver 20|H| through the onboard communication chip 14|H| or through a cellular connection which will allow for displaying on the dashboard touch screen device 30|H|. These messages that may be shown on the display 30|H| may include servicing requirements or tips to increase the efficiency of the vehicle 12|H|, such as checking tire pressure, battery temperature and the like.

[0326] Therefore, the above electric vehicle communication interface 10|H| has been described in one contemplated embodiment, however it should be noted that other contemplated embodiments and other methodologies that will allow for communication between the electric vehicle 12|H| and the user 20|H| and the passing of commands and monitoring of systems between the user 20|H| and the electric vehicle 12|H| and the manufacturer of the vehicle 12|H| are also contemplated and can be used in the scope of the electric vehicle communication interface 10|H| invention as described herein.

[0327] Referring to the drawings, a battery pack system 10|H| for an electric vehicle and any other industrial equipment is shown. It should be noted that the battery pack system 10|H| shown in the drawings is for use in an electric vehicle, however the battery pack system and battery cells may be used in any combination and in any design known for use in any number of industries including but not limited to any type of vehicle and any technology dealing with aerospace, marine, aviation, industrial equipment, and any other electrical system that has a need for protecting emergency responders or everyday users from electrocution and other injuries due to high voltage applications.

[0328] The battery pack system 10|H| has a tunable frangible conductor/wire 12|H| arranged between a plurality of battery cells 14|H| and a collector plate 16|H|. The use of the frangible battery pack conductor 12|H| will minimize the possibility of short circuiting and reduce potential exposure to high voltages by emergency responders or others in contact with the electric vehicles and industrial equipment. The battery pack system 10|H| of the present invention may include connections involving the battery cells 14|H| that will break at a predetermined impact and a predetermined thermal event. In one embodiment of the present invention the collector plate 16|H| will be connected to a plurality of battery cells 14|H| by the use of a narrow and thin conductor 12|H| such as a wire bond connection. It should be noted that the present invention may be designed such that the frangible conductor 12|H| is used within the battery pack system 10|H| to disconnect all of the battery cells 14|H| from some or all portions of the electrical circuits of the electric vehicle or to disconnect predetermined portions of the circuits from the battery cells 14|H|. Furthermore, the wire conductor 12|H| may be mechanically and electrically tuned to predetermined specifications to fail before the circuit reaches a predetermined threshold of extremely high heat or extreme forces applied thereto such that the battery pack system 10|H| may be accessible to emergency responders or other users of the electric vehicle without the threat of electrocution or injury. It should be noted that the system 10|H| generally is designed for use in an electric vehicle having a high voltage electric system. It should be noted that any of these vehicles may be any of the known auto vehicles such as passenger's vehicles, military vehicles, delivery vehicles and the like. Furthermore, the same technology has also been designed for use on aerospace, aviation, and marine sector vehicles and also industrial equipment that have any type of electric system and power supply. This technology may also be used in any other technologies such as but not limited to mining equipment, cranes, presses or the like. Therefore, the present invention of a frangible battery pack system 10|H| can be used with any known electric vehicle or electrical system industrial, personal or otherwise.
FIGS. 49 through 52 show a tunable frangible battery pack system 101 according to the present invention. The battery pack system 101 includes a housing 181. The housing 181 is generally a two piece clamshell housing that has a plurality of orifices 201 therethrough. The orifices 201 are generally circular in shape, however any other shaped orifice may be used. The housing 181 has a plurality of counter bores 221 arranged on each piece thereof. Each of the counter bores 221 will be used to hold and arrange therein a battery cell 141. The orifices 201 are arranged at or near a center point of the counter bore 221 of the housing 181. It should also be noted that it is contemplated to have a cooling tube arranged through the housing 181 to allow for cooling of the batteries 141 if need be. It should be noted that in one contemplated embodiment the housing 181 is made of a plastic material that is injected molded into the predetermined shape for the housing 181. However, it should be noted that any other type of material including metal, ceramic, composite, or natural material may be used for the housing 181 depending on the design requirements and environment in which the battery pack system 101 will be used.

Arranged within each counter bore 221 of the housing 181 is a battery cell 141. The battery cells 141 generally have a cylindrical shape in the embodiment shown. However, any other shape battery cell 141 may be used depending on the design requirements. The battery cells 141 are arranged within the counter bore 221 such that both ends of the battery cells 141 are exposed via the orifices 201 located at each end of the counter bores 221 through the housing 181. The end of the battery cells 141 will be used for electrical connection between the battery cells 141 and the collector plate 161.

The battery pack system 101 also includes a first collector plate 161 arranged on one end of the housing 181 and a second collector plate 161 arranged on another end of the housing 181. In one contemplated embodiment a single collector plate 161 will be used to cover one side of the housing 181. However, it is also contemplated to use multiple differently shaped and sized collector plates 161 on one side of the housing 181 and/or multiple collector plates 161 of different sizes and shapes on the opposite side of the housing 181. The collector plate 161 may have the same shape as that of the housing 181 and the shape may be of any known shape or diameter such as rectangular, triangular, square, circular, or any other known shape. Generally, the collector plate 161 is made of a metal material. However, it should be noted that the collector plate 161 can be made of any known material such as composite, any known metal, ceramic, natural material, plastic or any other material capable of conducting electricity. In one embodiment contemplated an electrolytic nickel plated aluminum or copper sheet metal will be used for the collector plates 161. The collector plates 161 will have a plurality of orifices 241 therethrough that will align with and mate with the orifices 201 through the housing 181 into the counter bores 221 of the housing 181. It should be noted that in one contemplated embodiment the orifices 241 are generally rectangular in shape, however any other shaped orifice 241 such as square, circular, triangular, pentagonal or the like may be used depending on the design requirements and environment in which the battery pack system 101 will be used. The collector plate 161 is secured to the housing 181 via any known connecting methodology. In one contemplated embodiment a combination of heat staking and epoxy will be used to connect the collector plate 161 to the housing 181. It should be noted that the orientation of the battery cells 141 within the housing 181, i.e., positive side up or positive side down and the size and shape of the collector plates 161 will allow for different designs and will create a unique and efficient method for creating a combination of parallel and series connections for the battery cells 141 within the electrical system of the electric vehicle. This will allow for many different designs and parameters to be achieved because of the variety of orientation of battery cells 141 within the housing 181 and the size and shape of the collector plates 161 that may be used to create both parallel and series connections within the electrical system. Furthermore, the battery cells 141 may be mounted in any other known type of matrix as long as the matrix is clad by a bus bar, collector plate or conductive plate 161.

Arranged between the battery cells 141 and the collector plates 161 are a plurality of frangible conductors 121 that create the electrical connection therethrough. Generally, the frangible conductor 121 is in the shape of a wire, however it is also contemplated to be in any other shape, such as a ribbon or the like. The conductor 121 generally is bonded to an end surface of the battery cell 141 and to the collector plate 161 at a predetermined position. In the embodiment shown the collector plate 161 may include a recessed portion 261 adjacent to the orifice 241 of the collector plate 161 that exposes the end of the battery cell 141. The recessed area 261 may be of any predetermined size and shape. In the embodiment shown the recessed area 261 is adjacent to each and every orifice 241 through the collector plate 161.

The frangible conductor 121 may also have any type of cross section other than a round or circular such as square, rectangular, triangular, or any other known cross sectional shape. In one embodiment contemplated the conductor 121 is generally made of an aluminum alloy material. Some aluminum alloy materials that may be used include but are not limited to 99.999% aluminum, 99.99% aluminum, 99% aluminum and 1% silicon, or 99.5% aluminum. It should be noted that any other type of metal, ceramic or composite material may also be used for the frangible conductor 121 according to the present invention. The frangible conductor 121 of the present invention may also include 0.5% by weight magnesium and 50 parts per million nickel along with the aluminum as described above. The use of the magnesium will add strength to the wire 121 which may help bond through any surface oxide that may be present on the battery cell 141 and collector plate 161. Furthermore, the nickel may provide a corrosion resistance effect to the frangible conductor 121 for the present invention. It should be noted that any other known substance may also be added to the conductor 121 along with or in place of one or both of the magnesium or nickel material. It should be noted that the frangible conductor 121 of the present invention generally is in the shape of a round wire that may drawn into any known diameter, however in the embodiment shown the diameter may be anywhere between 0.011 inches to 0.016 inches. In particular one diameter may be 0.012 inches or 0.015 inches. Furthermore, it is also contemplated that the frangible conductor 121 may be used in a ribbon form wherein the cross section of the ribbon may be within the range of 0.02 inches by 0.001 inches to 0.1 inches by 0.01 inches. In one contemplated embodiment a ribbon would have the form of 0.05 inches by 0.003 inches or 0.08 inches by 0.008 inches.

The frangible conductor 121 is connected to the end of the battery cell 141 and the collector plate 161 via any known connecting methodology both mechanical and chemical. The conductor is bonded to the battery cell 141 and to the collector plate 161 in one contemplated embodiment via an
ultrasonic wedge bonding process. However, it should be noted that any other ultrasonic bonding process along with any other type of welding process, mechanical crimping process, conductive epoxy process, soldering process, insulation displacement connectors, or any other known bonding process may be used to connect the frangible conductor 121 to both the collector plate 161 and the battery cell 141. In the contemplated ultrasonic wedge bonding process a bonding machine will feed out the conductor 121 either in the form of wire, ribbon or any other shape at a predetermined pace and will have it bonded to both the battery cell substrate and the collector plate substrate and cut the conductor 121 at an appropriate length. The ultrasonic wedge bonding process uses a computer controlled mechanism that can be programmed to place the wires 121 automatically and then use optical recognition or other methodology to validate and adjust the positions of the conductor 121 with relation to the battery cells 141 and the collector plate 161. It should also be noted that it is contemplated that the conductor 121 may only be used on one side of the battery cells 141 with or without a collector plate 161 while the other side of the battery cells 141 use another method such as but not limited to nickel strips, etc. It should further be noted that it is contemplated to directly connect the conductors 121 to the battery cells 141 without the use of the collector plate 161. These connections may be between adjacent battery 141 or in any other known configuration.

[0335] It should be noted that aluminum has been chosen as the preferred material for the conductor wire 121 because it is easily tunable to be a frangible conductor 121 for the following reasons. It may be bonded using the ultrasonic process, it is a low cost element and it has high thermal conductivity and low electrical resistivity, which will increase the durability and tunability of the battery pack system 101 in the electric vehicle. It should be noted that high thermal conductivity will allow a small cross section wire 121 to carry a current sufficient enough to operate in the high voltage applications. The small cross section furthermore is strong enough to support itself under normal operating conditions of the vehicle and battery pack system 101 but will not add significant strength to the battery pack system 101. This will ensure that the battery pack battery cells 141 will disconnect from the collector plate 161 when a predetermined mechanical force, overcurrent or thermal or a predeterminable mechanical force is applied to the battery pack system 101. It should be noted that the diameter, length and path of which the frangible conductor 121 is laid and arranged between the battery cell 141 and collector plate 161 can all be varied to allow for a predeterminated fatigue and fracture to occur at predetermined vibration levels, mechanical force levels, overcurrent levels and thermal levels which exceed any predetermined battery pack system 101 limitations throughout the entire electric vehicle operating system.

[0336] It should be noted that it is contemplated to provide an added level of mechanical support within the battery pack system 101, an added level of corrosion resistance, and arc suppression by use a silicone dielectric gel to fill the counter bore 221 around the battery cells 141 and cover the frangible conductor wire bond and wire 121. It should be noted that any other type of gel or other gel like substance may be used to provide the extra mechanical support, corrosion resistance and arc suppression as that of a silicone dielectric gel.

[0337] In operation, the battery pack system 101 will operate within the electric vehicle or industrial equipment to prevent electrocution and other injuries to first responders or users of such vehicle and equipment. In particular, in the event of an electric vehicle collision, crash or excessive shock, there is a chance that components within the electrical vehicle and specifically the battery cells 141 within the battery pack system 141 could break in a manner which is hazardous to the occupants of the vehicle, emergency responders, first responders, and any other people involved. In order to combat this potential injury situation the frangible conductor 121 is arranged between the battery cells 141 and collector plates 161 and is designed to break or disconnect the collector plate 161 from the battery cells 141 when a predetermined mechanical force is applied to the vehicle in the form of a shock, jolt or other excessive mechanical episode. It should be noted that the two primary hazards within the electric vehicle for which the frangible battery pack system 101 is best used are high voltages and thermal runaway of the battery cells 141 within the battery pack system 101. It should be noted that for the battery pack system 101 to develop a short, the battery cell parts need to move relative to each other and come in contact with one another. The frangible conductor 121 will break during this relative motion so that if there is contact between the batteries 141, the battery cells 141 will already be disconnected from one another and there will be no short circuit therefrom.

[0338] Under normal operating conditions of the electric vehicle the high voltage is created by the battery cells 141 are isolated from the occupants and emergency responders. In many failure modes the safety systems of the electric vehicle operating system further isolate the high voltages but in the most severe collisions, the high voltages may become accessible. Therefore, the frangible conductors 121 will help reduce the potential of electrocution and any electrical danger by disconnecting the battery cells 141 from the electrical vehicle car system and improve the abuse tolerance of the battery pack system 101. Hence, with the frangible conductors 121 made of, in one contemplated embodiment, aluminum wires from very specific alloys that are ultrasonically bonded to the battery cells 141 and to a collector plate 161 the ability to design and adjust the size, length, diameter, and specific materials added to the alloys of the frangible conductors 121 will allow for a variety of breaking points for the frangible conductor 121 tuned to specific mechanical forces encountered in electric vehicles such that a small five mile per hour bumper collision will not break the frangible conductors 121, however, higher force collisions, both front, rear and side and/or rollovers or piercing or high ending of an electric vehicle will allow for breaking and disconnecting of the battery cells 141 from the collector plate 161 and hence, the removal of short circuits and possible electrocution by first responders. However, the conductors 121 as designed will still provide adequate current carrying capability and mechanical strength during normal operations of the electrical vehicle.

[0339] Therefore, the present invention will allow for the mechanical, thermal and electrical behavior of the frangible conductor 121, in this case in the form of a wire, to be calibrated to predetermined values of any known electrical values, mechanical values and thermal values based on the design requirements and the environment in which the electrical vehicle or equipment will be used. Therefore, if mechanical, electrical and thermal scenarios beyond the designed operating conditions of the battery pack system 101 are encountered the conductors 121 will disconnect by some type of mechanical or thermal means. These thermal means may include but are not limited to an over current, runaway combustion products, runaway heating, electrical arcing,
reversal of battery cell voltage and high impedance connections. Examples of such mechanical means or occurrences through which the fragile conductors 12J may disconnect may include but are not limited to cyclic loading and fatigue, ultimate tensile strength and bonding failure in the interface between the battery cells 14J and the collector plates 16J. Hence, the tunable fragile battery pack system 10J is capable of being designed for any known electric vehicle application and will provide peace of mind and safety to first responders responding to accidents involving electric vehicles that have high voltage battery packs from fear of electrocution and other injuries during rescue of occupants within the electric vehicles during such situations.

[0340] Referring to the drawings, a method 10J and apparatus for deactivating faulty or bad battery cells from a battery pack for use in an electric vehicle or other industrial equipment is shown. It should be noted that the battery pack or energy storage system shown in the drawings is for use in an electric vehicle, however the battery pack and battery cells 12J may be used in any combination and in any design known for use in any number of industries including but not limited to any type of vehicle, or any technology dealing with aerospace, marine, aviation, industrial equipment, and any other equipment and any other electrical system that has a need for isolating or removing via deactivation faulty or bad battery cells within an electrical system.

[0341] The energy storage system or battery pack of the present invention is generally comprised of a predetermined number of battery modules or sheets, a main control and logic PCB and a twelve volt power supply. In one contemplated embodiment the energy storage system will have eleven battery modules or sheets capable of producing approximately 375 volts DC. The present invention may use batteries or cells 12J made of lithium ion cells in particular one embodiment uses commodity 18650 form factor lithium ion cells for the electric vehicle. The battery pack of the present invention operates at a nominal 375 volts and delivers approximately 240 horsepower to the motor of the engine. The energy storage system in one contemplated embodiment comprises 6831 individual lithium ion cells 12J wherein these cells 12J are electrically connected in parallel groups of sixty-nine cells 12J wherein each of these groups of sixty-nine cells constitute an electric module called a brick. The bricks are then connected in series within an individual battery module in the energy storage system called sheets. Each sheet or battery module is a single mechanical assembly and consists of nine bricks electrically connected in series. Each sheet generally has a nominal voltage of approximately thirty-five volts DC. Furthermore, each of the sheets may contain a mechanical mounting system, battery monitoring hardware electronics, and a thermal management system or cooling system as well as various safety systems to ensure proper protection for the vehicle and occupants of such vehicle. Each of these sheets will be rigidly mounted within an ESS enclosure and electrically connected to one another in series. The energy storage system may also include a battery monitor board that is associated with each sheet of the energy storage system and will monitor the voltage levels, temperature and other parameters of all bricks within its sheet.

[0342] Each of the cells 12J within the energy storage system (ESS) may be susceptible to a weak short circuit, a problematic weak short circuit, or a hard short circuit. A weak short circuit generally is internal to the individual cell 12J. These weak short circuits may be detected during the balancing of the batteries 12J via the battery monitor board wherein the capability of balancing by the battery monitor board is reduced such that the percentage of time that each brick is balancing, when the ESS is not in use, is tracked and monitored to determine which cell 12J has the weak short. A problematic weak short may be identified via the amount of energy that a single cell requires during balancing is more energy than the bleeder bricks or cells 12J are capable of providing thereto. This will signal to the vehicle management system and associated onboard computers of the electric vehicle that the cell 12J likely has a weak short and should be removed or isolated from the battery pack. A hard short may occur when a fuse in the form of a wire bond trips or breaks during a high voltage, high current, or high temperature situation or during a vehicle crash or other unusual circumstance affecting the electric vehicle and energy storage system.

[0343] The methodology 10J of the present invention is capable of detecting a weak short circuit, a problematic weak short circuit and a hard short as shown in FIGS. 53 through 55. The methodology 10J in one contemplated embodiment may check a battery monitor board 14J that is attached to each sheet of the energy storage system for balancing voltage of the cells 12J such that any required voltage balancing of the cells 18J is reported to a vehicle management system such that a weak short circuit cell 12J may be identified 18J and either isolated or removed 20J from the battery pack prior to point of customer delivery or prior to putting into the electric vehicles energy storage system. Any number of methodologies 16J for detecting which individual cell 12J has a weak short circuit therein may be used according to the present invention.

[0344] In one contemplated methodology 10J a weak short circuit may be detected through the battery monitor board wherein the battery monitor board will track which parallel group of cells 12J self discharges the most during a long vehicle period of rest. The group of cells 12J that self discharges the most during this period will allow the methodology to isolate which cell 12J has a weak short circuit and is constantly bleeding voltage from the cell 12J during non use of the electric vehicle. Another methodology contemplated to identify which cell may have a weak short circuit will track the amount of time each brick of the energy storage system requires resistive balancing. Those bricks that require the least amount of resistive balancing during the voltage balancing methodology may have the lowest capacity and hence, may have a cell 12J with a weak short circuit therein. Therefore, that brick would then be further examined by the methodology to identify which cell 12J has the weak short circuit within the brick.

[0345] It is also contemplated that when a problematic weak short circuit does occur that a methodology 10J may reduce the likelihood of having the weak short circuit affect the overall battery pack and individual cell 12J via thermal management of the battery pack to ensure that the individual cells do not get too hot or too cold which may lead to weak short circuits occurring within the individual battery cells. Furthermore, it is also contemplated to use a charge management methodology that may ensure that none of the individual battery cells 12J of the energy storage system are over charged during charging of the battery pack. The over charging of cells may create thermal shock to the cell and lead to a weak short circuit internal to the cells cathode or anode therein. Therefore, the probing by the methodology of the present invention or a trained service technician via the use of
a service manual associated with the electric vehicle of the present invention will ensure that the electric vehicle is checked for weak short circuit cells 12J prior to point of customer delivery or prior to putting the energy storage system into the electric vehicle for the consumer. If during this initial probing weak short circuits are detected the battery cell 12J may be isolated or removed from the battery pack system or the entire sheet of which the weak short circuited cell is located may be replaced prior to inversion in the vehicle or delivery to a customer.

[0346] One contemplated embodiment to detect, and isolate or remove a bad battery cell 12J from a multi cell battery pack would use an intelligent architecture of the present invention wherein that architecture is capable of finding and disconnecting any cell 12J with a weak short circuit therein. It should be noted that the present invention may be used with larger form factor cells and may provide a great advantage to such cells as the cost of the switches, printed circuit board assembly (PCB), fabrication and the like go down as the number of switches decrease within the energy storage system. It should be noted that in current battery architectures there generally is no way to disconnect a cell with a weak short circuit from the rest of a parallel group of cells without removing the module from the battery pack and physically breaking the electrical contact. This requires servicing of the electric vehicle which is inconvenient, expensive and time consuming for the manufacturer of the electric vehicle.

[0347] One method and apparatus to operate the intelligent architecture is to connect electrically in series with every cell 12J an electronically controlled switch 22J and an embedded processor 24J to control all of the switches 22J. In one contemplated embodiment the electronically controlled switch 22J will be arranged on a PCB 26J. The switch 22J may be in the form of a transistor, mosfet, fet, etc. It should be noted that in another contemplated embodiment the embedded processor 24J is arranged on the PCB 26J in the form of a PIC or any other known processor. It should be noted that the embedded processor 24J may also be arranged remotely from the battery pack and arranged on the battery monitor board, vehicle management system or any other on board computer within the electric vehicle. The apparatus will form an electrical network of switches for the entire energy storage system.

[0348] As shown in FIGS. 53 through 55 a cell 12J of the energy storage system is arranged within a clamshell member 28J, wherein the clamshell member 28J has a counter bore to receive and hold each of the cells 12J of the energy storage system. Arranged directly adjacent to the clamshell member 28J is a printed circuit board (PCB) 26J. A collector plate 30J is then attached to a top surface of the PCB 26J. Therefore, the PCB 26J will be sandwiched between a surface of the clamshell member 28J and a surface of the collector plate 30J. The PCB 26J may have arranged thereon at least one switch 22J and may in one contemplated embodiment have an embedded processor or microprocessor 24J arranged thereon. It should be noted that any methodology may be used to connect the battery cell 12J to the counter bore in the clamshell member 28J, the clamshell 28J to the PCB 26J and the PCB 26J to the collector plate 30J. An electrical connection 32J will then be made between the cell 12J and one side of the switch 22J on the PCB 26J. A second electrical connection 34J will be made from the opposite side of the switch 22J and a surface of the collector plate 30J. In one contemplated embodiment an ultrasonically bonded aluminum wire will be used to create the electrical connection 32J, 34J between the collector plate 30J and the switch 22J and the switch 22J and the battery cell 12J. However, it should be noted that any other methodology known or any other material may be used to create the electrical connection between the cell 12J and switch 22J and the switch 22J and collector plate 30J. The apparatus may also include a PCB trace 36J arranged between the PCB 26J and the embedded processor 24J in order to control the switch 22J.

[0349] It should be noted that an electric switch 22J may be connected to each and every cell 12J of the energy storage system. This will allow for each and every cell 12J to be individually removed or deactivated from the electrical system of the electric vehicle upon instructions from the embedded processor 22J, the vehicle management system or any other on board computer system. It should be noted that it is also contemplated to have the switch 22J in the form of a transistor or the like and to be integrated with the cell 12J directly thus removing the need for a PCB board to be arranged within the energy storage system of the present invention.

[0350] In operation the apparatus of the present invention can be used with any of the methodologies described above or may also be used with methodologies as described hereafter. In one such contemplated methodology during normal operation of the energy storage system all of the switches 22J would be closed thus connecting all cells 12J in the battery pack to one another. This methodology would be capable of detecting if a weak short circuit is anywhere within the battery pack by having the processor 24J detect which cell 12J has the weak short circuit by switching each cell 12J off; one by one, in the entire group of the battery pack. The embedded processor 24J will monitor each of the cells 12J during this switching off to determine if the short circuit persists in the system. If the short circuit does persist the processor 24J may be able to identify exactly which cell 12J needs to be switched off for the short circuit to stop within the battery pack system. This cell 12J that is identified as having the weak short circuit will be tagged by the microprocessor 22J and the microprocessor 22J then may permanently turn off the switch 22J to the bad cell 12J thus eliminating the weak short circuit from the electrical circuit of the energy storage system.

[0351] An alternate methodology will have all of the cells 12J in a normally open position such that the off state of the energy storage system will require no power. The methodology then, when the vehicle is to be charged or driven will, via a small supplementary battery, power the processor 24J embedded in the PCB 26J to close all of the switches 22J thus connecting all of the cells 12J to one another. The electric vehicle may then be driven, charged, and the external battery could be recharged at the same time. This methodology would also use the same switching of each cell off, one by one, to detect if a weak short circuit is occurring anywhere in the battery pack. When such a cell 12J is detected and identified to have a weak short circuit, that cell 12J will be left in the off state by the microprocessor 22J thus removing, deactivated or eliminating that cell 12J and the associated weak short circuit from the battery pack system. It should be noted that another advantage to this methodology is that in its initial state the battery pack and energy storage system will be inherently safer because the off state requires no power to be transmitted.

[0352] It should be noted that other methodologies and apparatuses may also be used in accordance with the present invention to isolate, identify and remove bad battery cells
from a multi cell battery pack. It is also contemplated that the methodology will try to prevent deep discharge of the battery via either audible or visual confirmation to the user of the vehicle. The vehicle management system may also help ensure that internal weak shorts do not occur in any of the battery cells. Therefore, any other methodology or apparatus capable of identifying, and disconnecting a bad battery cell having either a weak short, problematic weak short, or hard short is possible to be used according to the present invention.

[0353] Referring to the drawings, a battery pack thermal management system 20K for use with an energy storage system (ESS) 22K is shown. The energy storage system or battery pack 22K is generally comprised of a predetermined number of battery modules or sheets 24K, a main control and logic PCB, and a 12 volt power supply. In one contemplated embodiment the energy storage system 22K will have eleven battery modules or sheets 24K, which are capable of producing approximately 375 volts DC. This nominal voltage will operate an electric vehicle that will be capable of traveling many miles without recharging and is capable of delivering enough power and acceleration to compete favorably with or outperform internal combustion engines. In one contemplated embodiment the ESS 22K will be capable of storing enough energy that the electric vehicle can travel approximately 200 miles without recharging. However, it should be noted that it is also contemplated to have an electric vehicle based on the present invention, that can travel well over 200 miles without recharging. It is also contemplated in one embodiment that the electric vehicle using the energy storage system 22K of the present invention will be capable of accelerating from 0 to 60 miles per hour in approximately four seconds. No other electrical car known has produced this type of acceleration and mileage range without recharging.

[0354] The present invention may use batteries made of lithium ion cells 26K, in particular one embodiment uses commodity 18650 form factor lithium ion cells 26K for the electric vehicle. The battery pack 22K in the present invention stores the chemical energy equivalent of approximately two gallons of gasoline. The battery pack 22K operates at a nominal 375 volts and delivers approximately 240 horsepower to the motor. The energy and power capability of the battery pack 22K allow for the battery pack design and architecture to have many features that ensure the safety of the vehicle and its occupants during use of the electric vehicle. It should be noted that the lithium ion cells 26K are rechargeable such that after recharging, the batteries will be able to provide traction power for the vehicle based a fully recharged and capable battery. The energy storage system 22K in one embodiment comprises 6,831 individual lithium ion 18650 cells 26K that will allow for it to achieve the drive power and range necessary for the vehicle. These cells 26K are electrically connected in parallel groups of 69 cells wherein each of these groups of 69 cells constitutes an electric module called a brick.

[0355] The bricks are then connected in series within individual battery modules in the energy storage system 22K, called sheets 24K. Each sheet or battery module 24K is a single mechanical assembly and consists of nine bricks electrically connected in series. It should be noted that it is contemplated that the sheets 24K will be the smallest replacement unit within the energy storage system 22K. Each sheet 24K generally has a nominal voltage of approximately 35 volts DC. Furthermore, each of these sheets 24K contains a mechanical mounting system, battery monitoring hardware electronics, a thermal management system or cooling system 20K, according to the present invention as well as various safety systems to ensure proper protection for the vehicle and occupants of such vehicle. In the embodiment contemplated, eleven sheets 24K may be used in total to bring approximately 375 nominal volts DC to the energy storage system 22K, for use in the electric vehicle. Each of these sheets 24K will be rigidly mounted within an ESS enclosure 28K and electrically connected to one another in series. This series connection will create the nominal voltage of approximately 375 volts DC as described above. It should be noted that the ESS contemplated and shown in the present invention may be adjusted by either increasing or decreasing the number of sheets 24K and/or boards within the ESS 22K. The energy storage system 22K may also include a battery monitor board. A battery monitor board is associated with each sheet 24K of the energy storage system 22K. The battery monitor board monitors the voltage levels, temperatures and other parameters of all of the bricks within its sheet 24K.

[0356] Due to the high power output of the energy storage system 22K the individual cells 26K that comprise the ESS 22K must be thermally managed. This arrangement will increase and maximize the longevity of the energy storage system 22K. In the present invention the temperature of the cells 26K may be managed at the sheet 24K level wherein each of the cells 26K will benefit equally from the thermal management system 20K, regardless of its physical position within the sheet 24K. It should be noted that under the thermal management system 20K of the present invention each cell 26K is targeted to be within a temperature range of plus or minus 2 degrees within the energy storage system 22K. Furthermore, the thermal management system 20K of the present invention may provide for a method of thermally connecting each of the cells 26K in each sheet 24K, thereby thermally balancing each sheet 24K. Through the balancing of the sheets 24K maximum longevity, efficiency and power will be capable of being extracted from the energy storage system 22K. The ESS thermal management system 20K of the present invention removes heat from the energy storage system 22K to provide a cooling or chilling of the cells 26K, thus increasing the longevity and range of the electric vehicle on the road. This thermal management system 20K also is capable of adding heat or heating the cells 26K if such heating of the cells 26K is determined to be necessary via a vehicle management system and associated methodologies.

[0357] The electric vehicle according to one embodiment of the present invention may have a heating and cooling, and air conditioning system (HVAC) comprised of two loops, one for cabin cooling and heating and one for the energy storage system 22K cooling and heating. In one contemplated embodiment these two HVAC systems will be independently controlled. However, it should be noted that it is also contemplated to have both systems controlled by one independent component. The energy storage system 22K may be cooled via its loop by pumping an actively chilled fluid or coolant 72K through a cooling tube 30K which is arranged within each sheet 24K of the energy storage system 22K. The temperature of this fluid or coolant will be controlled by the HVAC system. In one embodiment the coolant will be chilled using a refrigerant-to-coolant heat exchanger. However, it should be noted that any other type of heat exchanger may be used depending on the design requirements and the electric vehicle in which the coolant will be used. In one embodiment
the refrigerant used may be a tetrafluoroethane, or R134A. However, it should be noted that any other known refrigerant may also be used in the system as described herein. In one embodiment the coolant that will be used will be a 50/50 mix of ethylene or propylene glycol and water. However, any other known coolant may also be used within the thermal management system 20K as described herein. The heat exchanger which may be used in one embodiment of the present invention will be a compact parallel plate heat exchanger wherein the heat is transferred from the coolant to the R134A refrigerant which is driven by the evaporated phase transformation of the refrigerant. In this cooling system 20K the coolant will enter and exit each sheet 24K of the energy storage system 20K via a manifold 32K. In one contemplated embodiment a coolant pump within each of the eleven sheets component of the HVAC system, however it should also be noted that it is contemplated that the coolant pump could also be located and/or controlled separately from the HVAC system according to the present invention. It is also contemplated to have the thermal management system 20K operate via a thermal electric methodology that may use a solid state “Peltier” device such that the thermal management system 20K would eliminate the need for refrigerant and also reduce the noise and vibration of the cooling system 20K for the energy storage system 22K. It should also be noted that any other known HVAC system and/or thermal management device that is capable of either removing heat or adding heat to a cell 26K may also be used in the present invention.

[0358] The thermal management of the energy storage system 22K according to the present invention is a continuously closed loop control system. In such system the temperature is monitored at a predetermined number of positions in each sheet 24K of the energy storage system 22K. In one contemplated embodiment the temperature will be monitored at six positions in each sheet 24K. The positions in each sheet 24K will be predetermined prior to insertion into the energy storage enclosure 28K. The six positions may be randomly or specifically chosen depending on location of the cells 26K within each sheet 24K. To monitor the six temperatures at the six positions within each sheet 24K a predetermined number of temperature monitoring devices 34K will be attached to the predetermined number of cells 26K within each sheet 24K. These temperature monitoring devices 34K will then be connected to the battery monitor board for each sheet 24K within the energy storage system 22K. In one contemplated embodiment the six temperature measuring devices 34K will be connected to the six different cells 26K within each sheet 24K such that the same six cells 26K within each sheet 24K will be monitored within the energy storage system 22K of the present invention. In one contemplated embodiment the temperature monitoring device 34K will be a thermistor 34K, however it is also contemplated to use thermocouples or any other temperature measuring device that is capable of being attached directly to a cell 26K to measure a temperature thereon. The temperatures will be transferred from the thermistors 34K via an electrical connection between the thermistors 34K and the battery monitor board. It should be noted that any type of electrical connection such as wire, wireless or any other known transfer technique can be used to transfer the temperature from each monitored cell 26K to the battery monitor board. Each sheet 24K within the energy storage system 22K has an individual battery monitor board related thereto. Each of these battery monitor boards, will report the temperatures of the six cells 26K within their sheet 24K along with other data to a battery safety monitor. The battery safety monitor will transfer these temperatures along with the other data to a vehicle management system.

[0359] The vehicle management system has overall control of the vehicle management and associated operating components. The continuous communication between the vehicle management system and the battery safety monitor will allow for an HVAC control board to determine the energy storage system 22K cooling requirements on a continuous basis. One contemplated control algorithm for the vehicle management system will be capable of intelligently predicting the cooling requirements based on the rate of discharge of a cell 26K versus the state of charge of the cells 26K within each sheet 24K. In one contemplated methodology if the energy storage system 22K reaches a zero state of charge before a maximum allowable operation temperature is reached then the vehicle management system would send a command and signal to not cool the energy storage system 22K. Also the control algorithm and the vehicle management system may be capable of reducing the parasitic power loss of cooling while the vehicle is driving by having the energy storage system 22K precooled during charging and at any time that the vehicle is connected to an AC power source. This reduction of the energy storage system 22K cooling demands while driving will result in the vehicle range being increased by a predetermined percentage. Furthermore, the vehicle management system may be capable of monitoring and avoiding condensation inside the ESS enclosure 28K, when the cooling of the energy storage system 22K is occurring via the thermal management system 20K. By measuring the temperature, humidity and calculating a dew point within the energy storage system enclosure 28K, a minimum cooling temperature for the energy storage system 22K may be maintained above a temperature where condensation becomes a risk. It should also be noted that another methodology to monitor and reduce condensation is also contemplated in the thermal management system 20K according to the present invention. This methodology uses a cold plate located within the energy storage system enclosure 28K, to force condensation to occur at a predetermined location within the enclosure 28K thus having the resulting liquid safely controlled and removed from the enclosure 28K. It is also contemplated that the thermal management system 20K of the present invention may reduce the cooling demand and hence the required energy needed by having the energy storage system enclosure 28K insulated which would help to reduce elevated ambient temperatures and hence condensation within the energy storage system enclosure 28K. These contemplated methodologies along with other contemplated methodologies are all controlled by the vehicle management system to intelligently predict cooling or heating needs of the energy storage system 22K and when such cooling should occur to provide for the most efficient use of the HVAC system and the most efficient use and increased longevity of the energy storage system cells 26K.

[0360] The thermal management system 20K also includes a manifold 32K that is fastened to an exterior surface of the ESS enclosure 28K. The manifold 32K may be fastened by any known technique such as a fastener, any mechanical fastening technique, any chemical fastening technique such as gluing, epoxy, welding, or the like. The manifold 32K generally is a double barreled or double cylinder extrusion. In one preferred embodiment the extrusion is made from an aluminum material. However, it should be noted that any other metal, ceramic, plastic, composite, natural material or
the like may be used for the manifold 32K. The two cylinder manifold 32K will have one of the cylinders 36K connected to the coolant pump on one end thereof, which is the input side for the thermal management system 20K of the energy storage system 22K. This input cylinder 36K of the manifold 32K will feed or pass the coolant from the coolant pump into the cooling tube 30K of each sheet 24K of the energy storage system 22K. The second barrel or cylinder 38K of the manifold 32K is the output side of the thermal management system 20K. After the coolant circulates through each cooling tube 30K arranged in each sheet 24K it will return via the second cylinder 38K to the HVAC system loop for recircling and recirculation within the ESS cooling system. The manifold 32K also may help the energy storage system 22K maintain equal flow and hence uniform temperature control within and among the plurality of cooling tubes 30K through symmetry of pressure gradients across the coolant flow path within the ESS cooling system 20K. Each of the cooling tubes 30K will have a predetermined length and cross section geometry that will be the same for each of the cooling tubes 30K. This will allow for the balance of the system 20K to be achieved through the design of the manifold 32K such that it will distribute the coolant evenly among the cooling tubes 30K. The cylinders 36K, 38K of the manifold 32K may be designed such that they have a diameter and length that are large enough to ensure that the pressure drop is much smaller than the pressure drop through a cooling tube 30K. This pressure drop which is inversely proportional to the flow through any of the given coolant paths within the energy storage system 22K will then approximately be equal to the pressure drop through one of the cooling tubes 30K. It is also contemplated in one embodiment to completely remove the effects of the pressure drop of the manifold cylinders 36K, 38K from the system 20K by having the inlet and outlet points of the coolant located at opposite ends of the manifold 32K. This will ensure that each coolant path has a pressure drop of one full cylinder length in addition to the pressure drop of the cooling tube 30K. It is also contemplated in another embodiment that the manifold 32K may be designed with progressively sized orifices to compensate for any pressure drop along the manifold 32K. The manifold 32K of the present invention may include a plurality of nozzles or flow members 40K extending from a surface thereof. The nozzles 40K may be used to move the fluid or coolant 72K from the manifold 32K to the cooling tubes 30K and back to the HVAC system. Also in another contemplated embodiment the ESS cooling system 20K may have a sacrificial anode arranged in the manifold 32K to reduce corrosion within the system 20K. The addition of this component would only require an orifice to be placed at a predetermined position in the manifold 32K and a metal or other material that is more readily corrodbale than aluminum to be attached thereto. This material would then corrode before the aluminum components in the thermal management system 20K and hence would be replaced before it dissolves completely thus ensuring the aluminum components of the system would not corrode.

The thermal management system 20K of the present invention also may include a cooling tube 30K arranged within each sheet 24K of the energy storage system 22K. In one contemplated embodiment the cooling tube 30K will be an extruded aluminum tube, however, it should be noted that any other type of metal, ceramic, plastic, composite, natural material or the like that is capable of extrusion casting or machining may also be used for the cooling tube 30K and all other components in the system 20K. It should also be noted that the cooling tube 30K must be thermally conductive. The cooling tube 30K of the present invention may be bent into a predetermined specific shape. One contemplated predetermined shape is shown in FIG. 60. This shape of the present invention includes a predetermined number of bends and corners therein. It should be noted that the shape can be of any random shape or any known shape depending on the positioning of the cells 26K within each sheet 24K of the energy storage system 22K. Therefore, any known shape or random shape may be used to form the cooling tube 30K for insertion into an energy storage system sheet 24K. It should be noted that an aluminum material for the cooling tube 30K was chosen for its resistance to elevated temperatures, its thermal conductivity, its light weight, and its manufacturability which will allow for the bending process to be made in a manufacturing setting without increased costs. In one contemplated embodiment the specific aluminum alloy used was a 6063 alloy. The 6063 alloy generally is a commonly extruded alloy. It should be noted that the cooling tube 30K of the present invention has a predetermined wall thickness that will allow for the thinnest wall possible thus reducing the weight of the final assembly, increasing the thermal conductivity of the cooling tube 30K and allowing for consistent bending of the cooling tube 30K during the entire manufacturing process. It should be noted that the final shape of the bent cooling tube 30K may have the two ends of the cooling tube 30K arranged adjacent to each other, however, any other final shape may also be used. It should be noted that a predetermined distance will separate the ends of the cooling tube 30K such that a connection of the cooling tube 30K to the manifold 32K may be easier for the manufacturer of the electric vehicle.

The cooling tube 30K in its extruded state will include a plurality of individual channels or lumens 42K arranged in an inner bore thereof. In one contemplated embodiment there is four individual channels 42K arranged along the entire length of the cooling tube 30K. It should be noted that the fluid or coolant delivery requirements of the cooling tube 30K according to the present invention only requires two such channels, however the additional two channels may be added to the cooling tube 30K to take advantage of the resulting two rib feature described hereafter. The cooling tube 30K may include two different types of ribs that will allow for the extruded cooling tube 30K to be formed into the required geometry by supporting the channels 42K during the bending process. It should be noted that generally to bend a two channel ribless tube it generally is necessary to fill the tube with sand, glass beads, or some similar type of material to prevent the channels from collapsing during the bending process. It should also be noted that collapsing a channel 42K within the cooling tube 30K would render the cooling tube 30K useless for fluid and coolant transfer, hence destroying the effectiveness of the thermal management system 20K, for the energy storage system 22K. Therefore, the ribs will enhance and create a sustainable manufacturing process for the energy storage system 22K and thermal management for the electric vehicle as described herein. The two rib system will include at least one dividing rib 44K and at least one supporting rib 46K arranged within the interior bore of the cooling tube 30K. In the contemplated embodiment shown in FIGS. 61 and 62 the dividing rib 44K will be arranged generally at or near a mid point of the cross section of the cooling tube 30K. A first supporting rib 46K in the contemplated embodiment shown in FIGS. 61 and 62 may be arranged
approximately half way between a side of the cooling tube 30K and the dividing rib 44K. Also, a second supporting rib 46K may be arranged at approximately a half way point between the dividing rib 44K and the opposite side of the cooling tube 30K. This will create a four channel 42K cooling tube 30K wherein the channels 42K run or extend the entire length of the cooling tube 30K, from a first end 48K to the second end 50K of the cooling tube 30K. It should be noted that it is contemplated to use any other type of configuration and number of channels within the cooling tube 30K including but not limited to two channels, three channels, five channels, six channels, seven channels, eight channels, etc. The use of the four channels 42K and hence three ribs will reduce the manufacturing costs by reducing the need to fill the tube 30K during the bending process into the predetermined bent shape.

[0363] After the cooling tube 30K has been bent into its predetermined shape the cooling tube 30K must be electrically isolated from the cells 26K. It should be noted that a thermally conductive frame or grid is also contemplated to be used in another embodiment to hold the cells 26K. It should be noted that to maximize the cooling potential of the thermal management system 20K the cell 26K layout and the sheet 24K have to be designed such that each cell 26K will be located close or very close to the cooling tube 30K within the sheet 24K. With the cooling tube 30K passing closely by each of the cells 26K, and with each of the cells 26K generally being at a different electric potential, electric isolation is necessary and important to the thermal management system 20K. Generally, to achieve this electrical isolation the present invention will have the cooling tube 30K coated with a material that will provide a continuous dielectric coating 52K. It should be noted that the electrically insulating coating 52K may only cover a portion of the cooling tube 30K. The uncoated portion may be submerged in the potting compound 74K. In one contemplated embodiment an electrical epoxy resin such as a 3M Scotchcast 5230N is used as the coating. However, it should be noted that any other type of coating capable of providing electric isolation for the cells 26K may also be used in the present invention. After the coating 52K is applied and dried the entire surface of the cooling tube 30K may be subjected to a hi pot test from approximately 2600 volts DC or 1835 volts AC to verify the electrical isolation of the cooling tube 30K.

[0364] After the cooling tube 30K is completely coated and tested for its electrical isolation the two adjacent ends 48K, 50K of the cooling tube 30K will be arranged within a tube seal plug 54K. The tube seal plug 54K generally has a cylindrical shape with a first and second orifice 56K, 58K that generally matches the outer surface of the cooling tube 30K. In the embodiment shown the orifices 56K, 58K generally have an oval shape to match or mimic the overall oval shaped cross section of the cooling tube 30K, according to the present invention. It should be noted that any other shaped cooling tubes 30K and orifices in the tube seal plug 54K may be used depending on the design requirements for the thermal management system 20K. Generally, the tube seal plug 54K may be made of any type of plastic. In one contemplated embodiment the tube seal plug 54K is made from a glass filled injection molded plastic. However, it should be noted that any other metal, ceramic, plastic, composite, or natural material may also be used for the tube seal plug 54K. It should also be noted that extruded cast or machined components may also be used for the tube seal plug 54K, cooling tube 30K or any other of the components of the thermal management system 20K according to the present invention. The two ends 48K, 50K of the cooling tube 30K may be secured to the tube seal plug 54K via any known bonding technique, i.e., a mechanical bond or a chemical bond. In one contemplated embodiment an epoxy adhesive will be used to secure the tube seal plug 54K to the two ends 48K, 50K of the cooling tube 30K. However, any other mechanical or chemical fastening technique may also be used. With the cooling tube 30K generally having curved surfaces and an irregular geometry the tube seal plug 54K creates a uniform surface on which to seal the ESS enclosure 28K at the point where the cooling tube 30K exits the ESS enclosure 28K. This seal will be achieved using a tube seal boot 60K which will be clamped onto the tube seal plug 54K and a predetermined ESS enclosure 28K via any known fastener. In one contemplated embodiment the tube seal boot 60K is made of a rubber material, however any other soft plastic, composite, natural material, etc., may be used for the tube seal boot 60K. It should be noted that any general circular clamp may be used to secure the tube seal boot 60K to the tube seal plug 54K and enclosure 28K, however any other fastening technique may also be used including but not limited to, chemical bonding techniques and any other mechanical fastening technique. Applicant has two prior pending U.S. applications relating to cooling tubes and cooling batteries or cells, having application Ser. Nos. 11/129,118 and 11/820,008 which are hereby incorporated by reference.

[0365] An end fitting 62K may be arranged over each end 48K, 50K of the cooling tube 30K after it is arranged within the tube seal plug 54K. The end fitting 62K generally has a first and second nipple 64K, 66K that extends from one end thereof. These nipples 64K, 66K allow for hoses 68K to be attached between the cooling tubes 30K and the nozzles 40K of the manifolds 32K. It should be noted that nozzles 40K of the manifold 32K may be designed with any known configuration to allow for a predetermined flow therethrough and into the cooling tubes 30K of the ESS cooling system 20K. Hence, an end fitting 62K may be placed on each end 48K, 50K of the cooling tube 30K such that two nipples 64K, 66K terminate from each end of the cooling tube 30K. It should be noted that the nipples 64K, 66K may include a plurality of beads thereon to improve hose 68K retention thereto. However, any other method of improving hose retention to the nipples 64K, 66K may be used including but not limited to chemical bonding techniques or any other known mechanical fastening technique. The end fitting 62K is arranged over each end 48K, 50K of the four channel cooling tube 30K such that the two nipple end fitting 62K has two adjacent channel 42K pairs combined and aligned into one isolated fluid path within the cooling tube 30K effectively yielding a two channel cooling tube 30K therein. Therefore, with an adjacent pair of channels 42K feeding and flowing into one nipple 64K on the end fitting 62K, a resulting increase flow of the coolant increases the heat transfer and efficiency of the thermal management system 20K for the energy storage system 22K. It should be noted that after the securing of the end fittings 62K and tube seal plug 54K to the cooling tube 30K, it is contemplated to have the cooling tube assembly leak tested to a predetermined pressure using compressed air. However, any other known leak testing technique may also be used. It should further be noted that one advantage of the present invention is that all fluid connections between the manifold 32K and the sheet 24K will be made outside of the ESS enclosure 28K thus
preventing any potential leak points from contaminating the cells 26K and other electrical components arranged within the enclosure 28K by leaks of coolant within the energy storage system 22K. Hence, after leak testing any leaks that may occur will occur on the outer surface of the enclosure 28K thus reducing any catastrophic failures of the sheets 24K within the energy storage system 22K and hence reducing costs to the manufacturer and users of the electric vehicle.

The thermal management system 20K of the present invention achieves uniform cooling of the sheet 24K via a counter flow architecture 70K of the coolant flowing through the sheet 24K of the energy storage system 22K. Without the use of this counter flow architecture the cells 26K located closer to the inlet side of the cooling tube 30K may benefit most from the heat transfer while those cells 26K located farther away would have a reduced benefit or may be no benefit at all. Generally, in one prior art heat transfer systems simply pumping coolant into one side of a cooling tube and out the other side would not suffice to provide a uniform cooling throughout the entire system. However, the thermal management system 20K of the present invention uses the counter flow architecture to pump coolant into only one of the nipples 64K of the end fitting 62K on one end 48K of the cooling tube 30K and into the opposite nipple 66K of the end fitting 62K on the other end 50K of the cooling tube 30K. The coolant 72K would then exit the sheet 24K, via the remaining two nipples on the end fittings 62K. This will ensure that uniform cooling will occur throughout the sheet 24K as the coolant 72K will be flowing in opposite directions within the cooling tube 30K via the channels 42K arranged therein. By connecting the manifold 32K as described, the use of the counter flow of the coolant 72K through the sheet 24K ensures that uniform cooling occurs throughout all of the cells 26K within the predetermined shaped sheet 24K of cells within the energy storage system 22K. It should be noted that in another contemplated embodiment the counter flow architecture may also be achieved by designing a predetermined end fitting that would cover both ends of the coolant tube 30K but would also allow for the cross counter flow architecture of the coolant flowing through the cooling tube 30K. The complexity of the end fitting 62K would be increased in such an alternate embodiment but it would also eliminate two coolant hose connections and thus four possible leak points per sheet 24K on the outer surface of the energy storage system enclosure 28K.

It should be noted that battery or cell life is prolonged at lower temperatures than those at higher temperatures. The HVAC system of the present invention may be used to keep the cells cool. However, it should be noted that power is required to run the HVAC system and that the driving range can be improved by minimizing the usage of the HVAC system in the present invention while driving. Therefore, it is contemplated that just before usage of the electric vehicle the HVAC system would be turned on and run a predetermined time using electricity from a typical power grid or the like. The use of the HVAC system before usage of the electric vehicle will effectively precool the batteries or cells 26K of the ESS thus leading to longer battery life and increased driving range for the electric vehicle. It should further be noted that the vehicle management system will not allow any charging of the cells below 0°C. Therefore, a first command may have to be given by the vehicle management system to slowly heat the cells to reach a 0°C temperature upon which charging may then begin of the battery pack. Furthermore, it should be noted that the vehicle management system will not allow use of the battery pack or electric vehicle below −20°C, however it should be noted that the electronics are still maintained at this temperature because the battery discharge can continue down to approximately −30°C. It should be noted that the temperature ranges given here are for just one contemplated embodiment and that any known temperature range may be used for the present invention. The electric vehicle is capable of driving when the battery pack is in the range of −20°C to 0°C, however charging cannot occur until the battery pack is heated to 0°C. Between 0°C and approximately 45°C charging of the battery pack and driving of the electric vehicle is permitted by the vehicle management system. Between 45°C and approximately 55°C power will be limited during charging and driving of the electric vehicle. At approximately 55°C and higher no operation will be permitted for the electric vehicle and battery pack because of the high temperature and risk of mitigation propagation or thermal runaway events therein. It should also be noted that based on the temperature ranges given above, which are all estimated and used in one contemplated embodiment, the heat point and humidity within the ESS will also be monitored to ensure dew does not form in the energy storage system or within the electric vehicle interior. It should be noted that any time frame can be used to begin the precooling with the HVAC system for the electric vehicle. In one contemplated embodiment thirty minutes before departure or usage of the vehicle such cooling may occur. However, it should be noted that any time frame from a few seconds to multiple minutes or hours may be used to effectively precool the battery pack and cells of the energy storage system according to the present invention. It should also be noted that all sensors associated with the ESS including but not limited to, temperature sensors, humidity sensors, voltage sensors, smoke sensors, inertia sensors, moisture sensors, and the like will be checked to ensure that appropriate conditions exist to either charge or use the battery pack for the electric vehicle of the present invention.

During assembly of the thermal management system 20K, a hose 68K or any other connecting member is placed on one nipple 64K, 68K of an end fitting 62K of the cooling tube 30K on one end thereof and the input cylinder 36K of the manifold 32K. The second input hose 68K would be arranged between the opposite nipple 64K, 66K on the other end fitting 62K on the opposite end of the cooling tube 30K and a nozzle 40K on the input side of the manifold 32K. The remaining nipples would be connected via a hose 68K or any other connecting member to the output side of the manifold 32K thus returning the coolant to the HVAC system for recirculating and other manufacturing techniques thereon.

During assembly of the energy storage system 22K the cooling tube 30K and cells 26K may be assembled into a lower clashing where thermal contact must be made between the cooling tube 30K and the cells 26K. The placement of the coolant tubes 30K next to the cells 26K may not be adequate because only line contact may be formed, thus thermal impedance may be very high within such a set up. Therefore, the present invention may increase surface contact between the cylindrical cell 26K and the generally flat cooling tube 30K. In one contemplated embodiment of the present invention a thermally conductive yet electrically isolative material 74K may be arranged between the cooling tubes 30K and the cells 26K. In one contemplated embodiment this material may be a two component epoxy encapsulant, such as
Stycast 2850/ct or any other potting compound. However, any other thermally conductive yet electrically insulative material 74K may also be used. This potting compound will thermally connect each cell 26K of the sheet 24K to the cooling tube 30K. With this thermal connection heat will be transferred from the cell 26K casing to the cooling tube 30K and then from the cooling tube 30K to the circulating coolant 72K. Depending on the environmental conditions of the energy storage system 22K this heat transfer may also function in the reverse direction. In particular, the cells 26K, and hence the energy storage system 22K, may be heated as well as cooled if necessary as determined by the vehicle management system. This heat may be generated either by an external electric heater or by reverse cycling the HVAC system which is contemplated for use in the electric vehicle. It should be noted that by thermally connecting each cell 26K to the cooling tube 30K the thermal impedance between the cells 26K may also be reduced. As a result, the cells 26K may benefit from thermal balancing even when the HVAC system is idle. Also, it should be noted that another advantage of the design of the present thermal management system 20K may be that the thermal mass of the energy storage system 22K may be increased by the overall effect of the potting compound 74K, the cooling tubes 30K and the coolant 72K compared to a prior art air cooled system. This increase in thermal mass may slow any temperature rise of the energy storage systems 22K compared to any of the prior art air cooled systems. It should be noted that in other contemplated embodiments a thermally conductive foam, paste, etc., may also be used in place of the potting compound. Furthermore, it is also contemplated that to help reduce the weight of the energy storage system 22K and hence electric car, thus increasing its range, micro spheres or other lightweight fillers may be added to the potting compound or other material thus reducing the overall weight of the electric vehicle. It should also be noted that the cooling tube 30K may be made of a compliant material and pressed into place between the cells 26K or may even include other features on its outer surface that will increase the surface contact area with the cells 26K within the energy storage system 22K. It should also be noted that the cooling tube 30K may be scalloped in such a way that surface contact between the cell casing and cooling tube 30K is increased, thereby improving heat transfer. It should be further noted that such scalloping allows for a more dense packaging of cells 26K, thereby reducing the size of the sheet 24K.

[0370] Referring to the drawings, a thermal event early detection system 20L is shown. The energy storage system or battery pack 22L is generally comprised of a predetermined number of battery modules or sheets 24L, a main control logic PSB, and a twelve volt power supply. In one contemplated embodiment the energy storage system 22L will have eleven battery modules 24L which are capable of producing approximately 375 volts DC. This nominal voltage will operate an electric vehicle that will be capable of traveling many miles without recharging and is capable of delivering enough power and acceleration to compare favorably with internal combustion engines.

[0371] The present invention may use batteries 26L made of lithium ion cells, in particular one embodiment used as commodity 18650 form factor lithium ion cells 26L for the electric vehicle. The batteries 26L of the present invention store the chemical energy equivalent of approximately two gallons of gasoline. The battery pack 22L operates at a nominal 375 volts and delivers approximately 240 horsepower to the motor. The energy and power capabilities of the battery pack 22L allow for the battery pack design and architecture to have many features that ensure the safety of the vehicle and its occupants during use of the electric vehicle. It should be noted that the lithium ion cells 26L are rechargeable such that after recharging, the batteries will be able to provide traction power for the vehicle based on a fully recharged and capable battery. The energy storage system 22L in one embodiment comprises 6831 individual lithium ion cells 26L that may allow it to achieve the drive power and range necessary for the vehicle. These cells 26L are electrically connected in parallel groups of six or nine cells wherein each of these groups of six or nine cells constitutes an electric module called a brick.

[0372] The bricks are then connected in series within individual battery modules 24L in the energy storage system 22L called sheets. Each sheet or battery module 24L is a single mechanical assembly and consists of nine bricks electrically connected in series. It should be noted that it is contemplated that the battery modules 24L will be the smallest replacement unit within the energy storage system 22L. Each battery module 24L generally has a nominal voltage of approximately thirty five volts DC. Furthermore, each of these battery modules 24L contains a mechanical mounting system, battery monitoring hardware electronics, a thermal management or cooling system, and an optical pyrometer 30L according to the present invention as well as various safety systems to ensure proper protection of the vehicle and occupants in such vehicle. Each of these battery modules 24L will be rigidly mounted within an ESS enclosure 28L and electrically connected to one another in series. It should be noted that the ESS 22L contemplated and shown in the present invention may be adjusted by either increasing or decreasing the number of battery modules 24L within the ESS 22L.

[0373] Due to the high power output of the energy storage system individual cells 26L the ESS 22L must be thermally managed. The individual cells 26L are arranged in predetermined patterns that can have any known pattern within the battery module 24L. The thermal management of these cells 26L may increase and maximize the longevity of the energy storage system 22L. In the present invention the temperature of the cells 26L may be managed at the battery module level wherein each of the cells 26L may benefit equally from the thermal management system regardless of its physical position within the battery module 24L. It should be noted that the thermal management system of the present invention includes early detection and mitigation of thermal events for any one individual cell 26L within the battery module 24L. Hence, the earlier possible detection of a cell 26L that is overheating occurs the earlier a control system 32L can initiate a cooling system 34L to provide for maximum full active cooling of the battery module 24L and associated cell 26L or the reduction of power demand via reducing current demand of cells 26L surrounding the cell 26L beginning to overheat during a thermal event. This early intervention, via early detection, will allow for the battery cell 26L to stop, reduce or control its overheating and thus limit the ability of thermal runaway to propagate throughout the entire battery module 24L which may result in the forced shutdown of the entire electrical system of the vehicle, battery module 24L and hence, affect the ability of the electric vehicle to operate and safely transport passengers.

[0374] It should be noted that internal and external factors may lead to the overheating of a battery cell 26L within a
battery module 24L. Generally, if a battery cell 26L reaches a sufficiently high temperature self-heating may begin within that cell 26L, which may eventually lead to a crossing of a critical threshold where all stored energy from that cell 26L is released as heat, thus affecting the surrounding cells with the excess heat delivered from that overheating cell 26L. Therefore, early detection of such thermal events may help prevent this condition from propagating to adjacent cells 26L in a battery module 24L via the early initiation of mitigation processes or methodologies that may include but are not limited to maximum active cooling of the affected cell 26L and/or battery module 24L or the reducing of the power demand from the surrounding battery cells 26L. The earlier these mitigation and proactive measures are implemented, the more effective they are in preventing propagation of this overheating cell 26L. The present invention may add another layer of protection in addition to already used methods such as but not limited to a combustion product sensor, etc., to prevent thermal runaway of the cells 26L and possible destruction or loss of the ESS 24L.

[0375] The increasing temperature of one battery cell 26L within a battery module 24L has the unintended consequence of increasing emission of infrared radiation at shorter wave lengths as a result of this temperature increase. The present invention will detect this increase in infrared radiation density within the battery module 24L using an electric signal from an optical pyrometer 30L. The optical pyrometer 30L detects infrared radiation emitted from a cell and sends an electric signal once a cell has reached a predetermined temperature. In one embodiment, the predetermined temperature is any temperature of 100° C. or greater. At this temperature the infrared radiation emitted from a hot or overheating cell 26L will be detected by the optical pyrometer 30L and such information then electronically sent to the control system 32L of the electrical vehicle. Generally, the inside of the battery module 24L of the ESS 22L is isolated from other sources of short wave radiation and a predetermined amount of infrared optical clarity exists within the battery module 24L such that changes in infrared energy density within the module are distinctly coupled or associated with the temperature of the cells. Therefore, a single or a predetermined plurality of optical pyrometer detectors 30L may be sufficient to identify the presence of the individual hot cell 26L at any location within the battery module 24L. The overheating cell 26L may propagate to surrounding cells 26L such that venting and the generation of combustion products may occur. Once venting and generation of combustion products occurs it may be too late to mitigate and stop the propagation of the thermal runaway from affecting all cells 26L within the battery module 24L. Hence, upon immediate identification of the overheating cell 26L mitigation measures will be implemented in the present invention.

[0376] The present invention includes a plurality of cells 26L closely packed within a battery module 24L which requires as one of its predetermined key safety features that a significant portion of the energy therein does not get released as thermal energy in one catastrophic thermal event. Hence, the ability to mitigate or stop one cell 26L from releasing its energy if it becomes too hot is necessary so as to prevent other nearby cells 26L from also becoming too hot and releasing all of their energy in a propagating cascade. It should be noted that a propagating thermal energy release may be triggered by a cell 26L reaching a critical threshold temperature. The maintenance of a sub-critical temperature in the surrounding cells 26L during the thermal event of the one overheating cell 26L may prevent an isolated thermal energy event from becoming a catastrophic event. Hence, the thermal energy from one cell 26L undergoing thermal runaway may be transferred to enough of the surrounding plurality of cells 26L to only increase their temperature slightly such that the thermal energy may be removed through full active cooling of the battery module 24L via a cooling system 34L arranged therein. These mitigation measures of switching on active cooling to its full power or decreasing the power demand/current demand from surrounding cells 26L may be used when such a thermal event is detected. The earlier the detection of any thermal event the more effective these mitigation measures will be.

[0377] Many thermal runaway events are now detected in prior art battery systems via the use of a combustion products detector. Generally, combustion products are produced when an individual cell reaches many hundreds of degrees Celsius and generally takes many tens of seconds or more to detect such a combustion product event. However, the present invention via the use of an optical detection system 20L may be capable of detecting a thermal runaway event almost instantaneously and at relatively moderate temperatures before the more noticeable consequences of a runaway thermal event occur, such as combustion products being released and detected. The present invention’s early detection of such thermal runaway of an individual cell 26L may provide the best chance of preventing thermal runaway propagation to multiple cells 26L within the battery module 24L.

[0378] The present invention uses the well known fact that objects emit radiation depending on their temperature and the emissivity of their surfaces. This thermal radiation is emitted from a surface in a broad distribution generally described by Planck’s formula for blackbody radiation. Radiation from these objects at different temperatures generally have profiles that are similar in shape but different magnitude and location on the frequency spectrum. Generally, warmer objects will emit more radiation and that radiation is at shorter wave lengths than cooler objects of the same type. Hence, the difference in both radiation quantity and the radiation wave length between an array of battery cells 26L at a predetermined normal temperature and a single cell 26L at a predetermined overheating or hot temperature is generally sufficient enough and significant enough to detect such overheating cell 26L at any position within a module. It should be noted that generally the normal temperature of the array of battery cells 26L within a battery module 24L of an electric vehicle of the present invention is less than 40° C. and that a cell 26L is considered to be overheating and nearing a hot temperature when it reaches approximately one hundred degrees Celsius or greater in temperature. However, it should be noted that depending on the design of the battery module 24L and cells 26L used therein, the normal temperature and temperature at which a thermal event appears to be beginning may vary within the range of 0° C. to 500° C.

[0379] The present invention achieves this thermal event early detection via the use of an optical pyrometer 30L arranged at a predetermined position within a battery module 24L of the ESS 22L. The optical pyrometer 30L may be placed at any position within the battery module 24L. The pyrometer 30L may be able to detect an increase in short wave radiation density within the module 24L wherein that short wave radiation density is associated with a single cell 26L within the battery module 24L that has become too hot and
has crossed a predetermined threshold temperature. In one contemplated embodiment as described above, the threshold temperature that indicates a cell 26L is becoming too hot is approximately 100°C. However, any other temperature may be used depending on the design requirements of the battery module 24L. Generally, the packaging of the battery cells 26L within the battery module 24L is such that the cells 26L have a reflective outer surface that is capable of reflecting photons off of their surfaces within the battery module 24L. This cell packaging will allow reflection of nearly 95% of photons at the infrared wavelength. Generally, the battery module 24L is designed such that no barriers are arranged within the battery modules 24L to the transport of this radiation within the module 24L such that the radiation spectrum at any point within the battery module 24L is capable of representing the components from every cell 26L within the module 24L. Therefore, the optical pyrometer detector 30L or any other known detector may be placed anywhere within the module 24L and still be capable of determining that one individual cell 26L within the battery module 24L is overheating based on detection of the short wave radiation density within that module 24L. It should be noted that in the embodiment shown, an optical pyrometer 30L is used to detect the short wave radiation density. However, any other detector capable of detecting any photon or radiation at generally infrared wave lengths may be used in the present invention. Also, it should be noted that if any one of the cells 26L becomes much hotter than the rest of the cells 26L within the battery module 24L, the magnitude and wave length of the admitted energy from this cell 26L will change such that the differences in the spectral energy density due to this overheating event of this one cell 26L may be detectable at any location within the module 24L by one detector 30L, however a plurality of detectors is also contemplated to be used in the invention to allow for earlier detection of such thermal events and/or corroboration of such thermal events occurring on an individual cell 20L via a plurality of detectors being controlled by a control system 32L of the electrical vehicle.

[0380] The optical pyrometer 30L is capable of being arranged anywhere within the battery module 24L and may be tuned to a single frequency in one contemplated embodiment or to a predetermined band of frequencies in another contemplated embodiment. The tuning of the optical pyrometer 30L to each individual battery module 24L and the cells 26L arranged within such modules will allow for a frequency sensitivity of the pyrometer 30L to be selected for predetermined cell temperatures that are expected to occur within the battery module 24L. This will allow all of the detectors to be maximally sensitive to the expected spectral energy density shift within each individual battery module 24L due to one cell 26L becoming hot within that individual battery module 24L. Therefore, if eleven battery modules 24L are required in an ESS 22L, such as that for one contemplated embodiment in the present invention, each optical pyrometer 30L may be tuned to a specific frequency wherein that frequency is different for each of the individual eleven battery modules 24L within the ESS 22L. However, it is also contemplated that each of the battery modules 24L may have the optical pyrometer 30L tuned to detect the same frequency across all battery modules 24L depending on the design requirements, specs, and tolerances of the battery cells 26L used in the electric vehicle. Generally, the frequencies that are chosen to be monitored by the optical pyrometer 30L are determined by using the Planck’s blackbody emission spectrum for each cell 26L and modeling the dispersion of such radiation from each cell 26L throughout the battery module 24L. Generally, an optical frequency may be chosen by examining the change in radiation energy density at the location of the pyrometer 30L within the battery module 24L and the sensitivity of the optical pyrometer 30L to the radiation energy density. The shorter wave lengths generally provide a larger differential signal between the radiation admitted by a hot cell 26L within a battery module 24L and the surrounding cells 26L within that same module 24L. The shorter wave lengths also result in lower overall radiation energy densities at their frequency being monitored.

[0381] The present invention may use an electronic signal from the optical pyrometer 30L to monitor the radiation energy density over the predetermined and chosen range of frequencies or frequency. This electronic signal will provide for an electronic communication between the optical pyrometer 30L and the control system 32L of the electric vehicle. It should be noted that the electronic signal may be transferred over a wireless network or a wired network depending on the design requirements and environment in which the electric vehicle and battery module 24L will be used. It should be noted that upon detection of short wave radiation at a density above a predetermined threshold which in one embodiment as described above results from at least one cell 26L within a module having a temperature at or above 100°C, the electronic optical pyrometer 30L will send an electronic signal to the control system 32L monitoring the pyrometer 30L. This control system 32L upon receiving such a signal detection of short wave radiation at a predetermined density will then initiate mitigation processes or methodologies to stop and/or control the overheating of that individual cell 26L. In one contemplated embodiment, such a mitigation process may involve full active cooling of that one individual cell 26L, the entire battery module 24L, or surrounding cells around the overheating cell 26L to allow for the surrounding cells to absorb such excess heat without entering thermal runaway. Another contemplated embodiment will use a mitigation process that reduces the current demand from the surrounding cells thus reducing the overall heat of the cells 26L surrounding the cell 26L having a thermal event thus allowing for the surrounding cells to absorb any excess heat without entering thermal runaway and propagating a thermal runaway event within the battery module 24L. It should be noted that any other known mitigation process or methodology that is capable of isolating the overheating cell or reducing the temperature of the overheating cell without leading to thermal propagation into surrounding cells and complete thermal runaway of the entire module is also capable of being used in conjunction with the early detection system 20L of the present invention.

[0382] The thermal event early detection system 20L of the present invention also may use in one contemplated embodiment a reflective surface 38L arranged within the module 24L at a predetermined position. The arrangement of this reflective surface or surfaces 38L within the module 24L may allow for a decrease in the absorption and transmission of infrared radiation at or through the outer walls of the battery module 24L. Furthermore, the use of a single or plurality of reflective surfaces 38L may also be used to direct the flow of the infrared radiation within the battery module 24L to a predetermined position thus decreasing in the detection time of a overheating cell 20L by the optical pyrometer 30L within the battery module 24L. Generally, if each of the battery cells 26L.
within the battery module 24L is capable of being seen or detected by the optical pyrometer detector via a predetermined small number of reflections off of the reflective surfaces 38L. The required sensitivity of the optical pyrometer detector 30L may be greatly reduced, thus reducing the cost and time for detection of such thermal runaway event thus increasing the chances that the thermal runaway event will not propagate into the surrounding cells 26L.. Reflective surfaces 38L may also serve to reduce the quantity of optical pyrometer detectors 30L required. The increased durability and longevity of the cells 26L within the ESS 22L may increase the value of the electric vehicle to the consuming public. Furthermore, the reduction of excess thermal heat within a battery cell 26L may increase the efficiency of the battery cells 26L and overall battery modules 24L thus increasing the amount of power capable of being provided by the battery modules 24L to the electric vehicle thus increasing the range of the electric vehicle for the consuming public. It should be noted that the use of the reflective surfaces 38L inside of the battery module 24L, wherein that battery module 24L generally is sealed from outside light, allows the infrared radiation to scatter inside of the module 24L and be detectable above a certain density of short wave radiation. Generally, in one contemplated embodiment, the photon transistor in the form of the optical pyrometer 30L may be sensitive at 1000 to 4000 nanometers which, for a Plank distribution, is shorter wavelength than a 50° C. peak but within a 100° C. curve. In one embodiment, the pyrometer 30L may be lead sulfide or lead selenide however any other known type of optical pyrometer 30L may also be used. This will allow for a cell that reaches the threshold temperature of approximately 100° C. to be detected by a single photon detector 30L within a module of generally 50° C. cells 26L therein. It should be noted that the present invention has been described for use in an electric vehicle, however it may be used in any other type of electrical system that uses a battery pack or energy storage system to provide power to any known vehicle, industrial machine, or any other system using electricity in operation thereof.

[0383] Referring to the drawings, a battery pack thermal management system 20M used with an energy storage system (ESS) 22M is shown. The energy storage system or battery pack 22M is generally comprised of a predetermined number of battery modules or sheets 24M, a main control logic PSB, and a twelve volt power supply. In one contemplated embodiment the energy storage system 22M has eleven battery modules or sheets 24M, each of which is capable of producing approximately 375 volts DC. This nominal voltage may operate an electric vehicle that will be capable of traveling many miles without recharging and is capable of delivering enough power and acceleration to compare favorably with internal combustion engines. In one contemplated embodiment, the ESS 22M may be capable of storing enough energy that the electric vehicle can travel approximately 200 miles without recharging. However, it should be noted that it is also contemplated to have an electric vehicle based on the present invention that can travel well over 200 miles without recharge. It is also contemplated in one embodiment that the electric vehicle used in the energy storage system 22M of the present invention will be capable of accelerating at speeds comparable to an internal combustion engine vehicle. No electrical car is known to produce this type of acceleration and mileage range without recharging.

[0384] The present invention may use batteries made of lithium ion cells 26M, one contemplated embodiment uses commodity 18650 form factor lithium ion cells 26M for the electric vehicle. The batteries 26M of the present invention store the chemical energy equivalent of approximately two gallons of gasoline. The battery pack 22M operates at a nominal 375 volts and delivers approximately 240 horsepower to the motor. The energy and power capabilities of the battery pack 22M allow for the battery pack design and architecture to have many features that ensure the safety of the vehicle and its occupants during use of the electric vehicle. It should be noted that the lithium ion cells 26M are rechargeable such that after recharging, the batteries will be able to provide traction power for the vehicle based on a fully recharged and capable battery. The energy storage system 22M in one embodiment comprises 6831 individual lithium ion cells 26M that may allow it to achieve the drive power and range necessary for the vehicle. These cells 26M are electrically connected in parallel groups of nine cells wherein each of these groups of nine cells constitutes an electric module called a brick.

[0385] The bricks are then connected in series within individual battery modules in the energy storage system 22M called sheets 24M. Each sheet or battery module 24M is a single mechanical assembly and consists of nine bricks electrically connected in series. It should be noted that it is contemplated that the sheets 24M or cells 26M may be the smallest replacement unit within the energy storage system 22M. Each sheet 24M generally has a nominal voltage of approximately thirty five volts DC. Furthermore, each of these sheets 24M contains a mechanical mounting system, battery monitoring hardware electronics, a thermal management or cooling system, as well as various safety systems to ensure proper protection of the vehicle and occupants in such vehicle. In the embodiment contemplated, eleven sheets may be used in total to bring approximately 375 nominal volts DC to the energy storage system for use in the electric vehicle. Each of these sheets 24M will be rigidly mounted within an ESS enclosure 28M and electrically connected to one another in series. It should be noted that the ESS 22M contemplated and shown in the present invention may be adjusted by either increasing or decreasing the number of sheets and/or bricks within the ESS 22M.

[0386] The high power output of the energy storage system 22M and associated individual cells 26M that comprise the ESS 22M must be thermally managed. This management will increase and maximize the longevity of the energy storage system 22M. The temperature of the cells 26M may be managed at the sheet level wherein each of the cells 26M may benefit from the thermal management system 20M regardless of its physical position within the sheet 24M. It should be noted that the thermal management system 20M of the present invention maintains each cell 26M within a predetermined temperature range within the energy storage system 22M. Furthermore, the thermal management system 20M of the present invention may provide for a method of thermally connecting each of the cells 26M in each sheet 24M, thereby thermally balancing each sheet 24M. Through the balancing of the sheets maximum longevity, efficiency and power will be capable of being extracted from the energy storage system 22M. The thermal management system 20M of the present invention removes heat from the energy storage system 22M to provide a cooling or chilling of the cells 26M, thus increasing longevity and range of the electric vehicle on the road. The thermal management system 20M may also be capable of adding heat if the cells require such. It should also be noted that the thermal management system 20M is capable of mili-
gating or stopping thermal runaway of a battery cell 26M within the energy storage system 22M.

[0387] The electric vehicle according to one embodiment of the present invention may have a heating ventilation air conditioning (HVAC) comprised of two loops, one for cabin cooling and heating and one for energy storage system 22M cooling and heating. In one contemplated embodiment these two HVAC systems will be independently controlled. However, it should be noted that it is also contemplated to have both systems controlled by one independent controller. The energy storage system 22M may be cooled via its loop by pumping actively chilled coolant or fluid through a cooling tube 30M which is arranged within each sheet 24M of the energy storage system 22M. The temperature of this fluid or coolant will be controlled by the HVAC system. In one embodiment the coolant will be chilled using a refrigerant-to-coolant heat exchanger, however it should be noted that any other type of heat exchanger may be used depending on the design requirements of the electric vehicle in which the coolant will be used. Any type of coolant may be used within the system. It should also be noted that the heat exchanger in one embodiment contemplated will be a compact parallel plate heat exchanger wherein the heat is transferred from the coolant to the refrigerant. In this cooling system the coolant will enter and exit each sheet 24M of the energy storage system 22M via a manifold 32M. It should be noted that any known HVAC system and/or thermal management device that is capable of either removing heat or adding heat to a cell 26M may be used in the present invention. It is also contemplated to use a coolant to air heat exchanger for the present invention.

[0388] The thermal management system 20M according to the present invention is a continuously closed loop control system. The temperatures in the system are monitored at a predetermined number of positions in each sheet 24M of the energy storage system 22M. Each sheet 24M within the energy storage system 22M has an individual battery monitoring board related thereto. Each of these battery monitoring boards will report the temperatures of the cells 26M within the sheet 24M along with other data to a battery safety monitor. A vehicle management system may be capable of operating numerous methodologies and algorithms to effectively control the thermal management system 20M and the amount of cooling provided to the cells during numerous operating parameters of the electric vehicle and associated energy storage system 22M.

[0389] The Applicant has filed a co-pending application that describes a thermal management system in detail and that application is hereby incorporated by reference.

[0390] The thermal management system 20M includes a manifold 32M that is fastened to an external surface of the ESS enclosure 28M. The manifold 32M is generally a double barred or cylindrical extrusion. However, any other type or shape of manifold 32M may also be used. The manifold 32M may be in fluid communication with the cooling tube 30M according to the present invention. The manifold 32M may also help the energy storage system 22M to maintain equal flow and hence, uniform temperature control within and among the plurality of cooling tubes 30M through symmetry of pressure gradients across the coolant flow path within the ESS cooling system. The thermal management system 20M of the present invention also includes a novel and improved cooling tube 30M arranged within each sheet 24M of the energy storage system 22M. In one contemplated embodiment, the cooling tube 30M has an optimized geometry that will allow for an optimization of volumetric packing density of nested vertically aligned cells 26M within the ESS 22M and also minimize thermal resistant between the cooling tube 30M and the cells 26M. It should be noted that the cells 26M generally have a cylindrical shape. The optimized shaped cooling tubes 30M of the present invention may provide for temperature control during operation and mitigation of thermal runaway events within the energy storage system 22M of the electric vehicle. The cooling tube 30M is arranged between adjacent rows of cells 26M. The cells 26M may be arranged in rows offset by one half of the cell spacing in a single row. The rows will be capable of nesting together to a desired separation. In one contemplated embodiment, this separation will have a nominal distance of approximately 0.5 millimeters, however any other separation from a few microns up to multiple millimeters is also contemplated for the present invention. The remaining space arranged between cells 26M will be filled by the cooling tube 30M having a specific optimized shape according to the present invention. This will ensure closer contact and closer cell spacing which will have the added benefit of low thermal resistance and a reduced battery pack energy density.

[0391] The cooling tube 30M of the present invention has an optimized geometry that generally has a scalloped shape. It should be noted that any other optimized shape may be used, but in the embodiment shown, a scalloped outer shape on the outer surfaces of the cooling tube 30M is used. The scalloped version of the cooling tubes 30M will have a plurality of contours 34M arranged along each side surface of the cooling tube 30M. The contours 34M may extend the entire length of the cooling tube 30M or for a predetermined portion of the cooling tube 30M. The contours 34M will generally have a predetermined shaped bend arranged along each side of the cooling tube 30M. The contours 34M along the surface of both sides of the cooling tube 30M may extend along and against the surface of the cells 26M circumferentially at a constant offset until a point of minimum separation between the cells 26M and the next nesting cell 26M of the opposite row is achieved. The cooling tube 30M then will transition via an inflection or shift 36M and begin to contour around a cell 26M on the opposite row. This practice of contouring and inflecting to maintain minimum separation between the cooling tube 30M and the cells 26M may provide for a maximum thermal proximity along the entire length of opposing rows of cells 26M within the sheet 24M. The cooling tube 30M according to the present invention may have a high aspect ratio which may minimize its impact on the axial pitch between the rows of cells 26M and maximize the thermal contact between each cell 26M and the cooling tube 30M. It should be noted that the inside radius of each scallop or bend 34M of the cooling tube 30M is approximately equivalent to the outer radius of each cell 26M plus a nominal minimal spacing between the cell 26M and the scallop cooling tube 30M.

[0392] The cells 26M of the present invention being arranged around the scallop tubes allows for higher density energy storage and higher power operation at lower cell temperatures and/or increased protection against cell to cell propagating thermal runaway. The nesting of the adjacent rows of cells 26M wherein the rows are offset by one half of the cell spacing in a single row, will allow the cooling tube 30M of the present invention to fill up substantially all of the cavity formed by the network of cells 26M, thus allowing for a tighter packing of each sheet 24M of cells 26M. The geom-
tery of the scalloped tube 30M will allow for the bends 34M to follow the contour of each cell 26M, thus providing for a wide area of minimum desired separation ensuring close thermal contact. The size and weight of the battery module 24M is one of the primary limitations for the amount of energy capable of being stored in the electric vehicle. The use of the scalloped cooling tube geometry 30M may allow for more energy to be carried for a given module size and weight within the electric vehicle. Furthermore, the geometry of the scalloped cooling tube 30M may provide benefits to the performance of the energy storage system battery modules 24M.

[0393] In some cell heat generation conditions including those greater than 1°C during discharge and during thermal runaway conditions some other geometries may be insufficient to prevent undesirable cell temperatures. During high discharge rates the high thermal resistance between some prior art tubes and cells may result in a requirement to reduce the power output of the battery module. In addition, many of these prior art battery modules that have cooled below their minimum operating temperature may contribute to an unacceptably long warm up period. The scalloped cooling tube 30M and any other contemplated optimized geometry may decrease the thermal resistance by approximately a factor of two which will allow for higher power operation and shorter warm up times as well as adding increased protection against thermal runaway propagation according to the present invention. The use of the scalloped tubes 30M may allow for configurations with high energy storage density, a higher degree of safety and the means to maintain the temperature of the cells at moderate levels according to the present invention. The scalloped tube geometry disclosed herein may provide an energy density that is greatly improved by decreasing the axial pitch between rows of cells 26M by approximately 10% over other cooling tube configurations. This 10% decrease is generally due to the closer nesting of the cells 26M to one another. It should be noted that the 10% decrease is an approximation and any other percentage decrease may also be achieved depending on the optimized geometry used for the cooling tubes 30M. The scalloped tube geometries also may have a direct impact on the volumetric energy density while also impacting the gravimetric energy density by removing excess packaging and thermally conductive media from between the cells 26M and the optimized geometry cooling tubes 30M. It should also be noted that the scalloped tube geometry according to the present invention may provide a two dimensional patch of minimum separation by contouring circumferentially around each cell 26M on both sides of the cooling tube 30M. It is also contemplated to use a thermally conductive medium 38M between the cell 26M and scalloped cooling tube 30M, which will decrease thermal resistance by up to a factor of approximately two for minimum separation distance of approximately 0.5 millimeters with greater reductions occurring for smaller separation distances. These lower thermal resistances may also allow higher cell power delivery for longer time periods in addition to allowing faster warm up time when the cells are being actively heated to their minimum operating temperature for equivalent fluid flow conditions. Furthermore, each scalloped cooling tube 30M may allow for lower thermal resistance which may allow the electric vehicle designers to change the cooling system, for example by changing the coolant refrigerant heat exchanger to a coolant air heat exchanger thus reducing the weight and complexity of the electric vehicle.

[0394] It should also be noted that a primary advantage of the optimized cooling tube geometry according to the present invention is the prevention of propagation of thermal runaway from cell to cell within the energy storage system 22M. Generally, when an individual cell 26M enters this condition, the heat generated must either be removed by active cooling and/or absorbed by enough surrounding cells to not sufficiently heat any one individual adjacent cell to a point that it also enters thermal runaway. It should be noted that the approximate factor for reduction and thermal resistance between a cell 26M and the scalloped cooling tube 30M generally creates the potential for the mitigation and possible prevention of propagating thermal runaway within the energy storage system 22M by bringing the cells 26M in closer thermal contact with the cooling tube 30M and fluid contained within. Close thermal contact with the fluid may allow for boiling heat transfer to transport heat to many surrounding cells 26M and close thermal contact with the cooling tube 30M may allow heat to conduct down the tube 30M to be absorbed by many surrounding cells 26M. If enough surrounding cells 26M absorb the heat generated by the runaway event, the propagation of the event may be halted. It should be noted that the factor of two reductions in thermal resistance is an approximation and the factor may either be larger or smaller depending on the design requirements of the energy storage system. It should be noted that the width of the scalloped cooling tube 30M may be between a half millimeter up to twenty millimeters depending on the design requirement and the energy storage system 22M being used in the electric vehicle. The length and height of the cooling tube 30M may be of any known dimension. The inner radius of the scallops 34M of the cooling tube 30M according to the present invention may be any known size along with the outer radius of the cells 26M may be of any known dimension as long as the inner radius of the scallop 34M of the cooling tube 30M and the outer radius of the cell 26M are approximately equivalent or the same to one another thus allowing for close thermal contact between the cells 26M and the cooling tube 30M.

[0395] The cooling tube 30M may have a plurality of lumens or channels 40M arranged within the inner bore of the cooling tube 30M. The channels 40M allow for coolant to flow through the cooling tube 30M at a predetermined pressure. The channels 40M allow for fluid to flow in opposite directions within the same tube 30M. This counterflow allows heat transfer between the opposing fluid flows, presenting a more uniform coolant temperature to the cells 26M and improving the thermal balance of the cells 26M within the sheet 24M. In addition, the channels 40M also allow for the cooling tube 30M to be bent in to predetermined shapes without collapsing the tube upon itself.

[0396] It should be noted that the tube 30M may be bent into any predetermined shape that will accommodate the predetermined arrangement of the cells 26M and the sheets 24M within the ESS 22M. In one contemplated embodiment the cooling tube 30M may have both ends of the tube arranged adjacent to one another and secured within a tube seal plug. On each end of the cooling tube 30M there may be an end fitting that will be used to connect the cooling tubes 30M to the manifold 32M via a hose or any other type of connector material. It should be noted that in one contemplated embodiment the scalloped cooling tube 30M is made of an aluminum material. However, it should be noted that any other type of metal, ceramic, plastic, composite or natural material may be used for the cooling tube 30M.
The scalloped cooling tube 32M according to the present invention may be manufactured in a number of contemplated embodiments. In one contemplated manufacturing setting a press 44M will be used. The press 44M may have nesting horizontal cylinders 42M arranged in arrays on either side of the cooling tube 30M. These horizontal cylinders 42M will serve as dies and will allow for the predetermined scallops or bends 34M to be arranged along both sides of the cooling tube 30M. Another contemplated embodiment for creating the scalloped shape cooling tubes 30M would be to feed a straight cooling tube through a pair of rollers that have curved, scalloped and interlocking protrusions extending therefrom. The shape of these protrusions will define the radii of the scallops produced and the spacing of the rollers may be adjustable for tubes of various widths. Still another contemplated embodiment for making the scalloped cooling tubes 30M according to the present invention may involve taking a pre-bent tube 30M and pressing the indentations, bends or scallops in parallel using a die 46M that has several rolls of scalloped surfaces as shown in FIG. 79. This will allow for improved manufacturing tolerances of the bent cooling tube 30M beyond that which may be achievable in tube bending through plastic deformation of the tube in the die. These close tolerances will allow for minimum separation distance between the cells 26M and the scalloped cooling tube 30M to be reduced, thus further improving thermal performance and energy density of the overall battery pack 22M. Generally, these methods are performed on cooling tubes 30M that start as flat tubes and have multiple lumens or channels 40M arranged in their inner bore such that collapse of the tube 30M is reduced or completely eliminated. It should be noted that other manufacturing methods are contemplated to create this scalloped cooling tube 30M for use in an energy storage system 22M according to the present invention.

The scalloped cooling tube 30M of the present invention must have optimal thermal contact between both sides of the tube 30M and adjacent rows of cells 26M within the energy storage system 22M. In one contemplated embodiment, a deformable thermal pad 38M may be arranged between the scalloped cooling tube 30M and the cells 26M on each side thereof. This deformable thermal pad 38M may provide an intimate thermal contact along the entire height of the tube 30M for the full area that the cooling tube is in contact with or wraps around the cells 26M. The use of this pad 38M may reduce the need for other thermal transfer media such as potting compound that is contemplated to be used in other contemplated embodiments. It should be noted that it is contemplated to use the pad 38M in conjunction with a potting compound or other thermal transfer media to provide the best thermal transfer between the scalloped cooling tube 30M and the cells 26M. The thermal pad 38M may be deformable enough to ensure that a varying gap between the cooling tube 30M and cells 26M will ensure contact between the cell 26M and tubes 30M via the provided compression necessary to utilize the thermal properties of the thermal pad. Such a compressible thermal pad 38M may allow that any dimensional variations within the manufacturing tolerances of the cooling tube 30M or cells 26M may ensure proper thermal connection between the cells 26M and the scalloped cooling tube 30M. It is also contemplated to have the pads 38M secured to the cooling tube 30M via a plurality of outward extending members or catches extending from the surface of the cooling tube 30M which will interact with and hold the thermal pad 38M at a predetermined position with relation to the outer surface of the cooling tube 30M. It is also contemplated to use an adhesive or other type of fastening compound to secure the thermal pad 38M to the side of the cooling tubes. It is also contemplated for the cooling tube 30M to be used in association with the thermal pad 38M, wherein the thermal pad 34M may have one side cured to a smooth non-sticky surface or have one side coated with a laminate that is electrically insulating to provide electrical isolation and the appropriate thermal contact between the cell 26M and cooling tubes 30M. It should be noted the thermal pad 38M may be used on one side, both sides, or neither side of the cooling tube 30M according to the present invention.

It should be noted that the scalloped cooling tube geometry that is shown in the drawings is only one of many contemplated embodiments for an optimized tube geometry that will be capable of filling any shaped gap between any shaped array of nested battery cells 26M within the energy storage system 22M. Other contemplated embodiments for optimized tube geometries may include a cooling tube that is hydro formed into a void resembling the rows of cells arranged within each sheet 24M which would provide similar benefits to the scalloped cooling tube 30M of the present invention and may allow for high tolerances. Still another contemplated optimized tube geometry may be a cooling tube formed in a T extrusion where the top portion of the T is solid and the remainder portion has a closed void for fluid flow. The top of this T extrusion may be stamped from the top to form cutouts that may fit the profile of the rows or the battery cells within the sheets. The close contact between the cells and the T extrusion cooling tube may provide low thermal resistance between the cells and the coolant. Still another contemplated optimized tube geometry may include a scallop tube 30M having an extruded fin extending from one edge of the body with locating holes that would aid in positioning of the cooling tube during manufacturing and assembly of the thermal management system within the energy storage system.

Referring to the drawings, a system 10N for mitigation of propagation of a thermal runaway event in a multi-cell battery pack for use in an energy storage system (ESS) 12N is shown. The energy storage system or battery pack 12N is generally comprised of a predetermined number of battery modules or sheets 14N, a main control and logic PCB 51N and a twelve volt power supply 16N. In one contemplated embodiment the energy storage system 12N will have eleven battery modules or sheets 14N which are capable of producing approximately 375 volts DC. This nominal voltage will operate an electric vehicle that may be capable of traveling many miles without recharging and is capable of delivering enough power and acceleration for everyday driving use. In one contemplated embodiment the ESS 12N may be capable of storing enough energy that the electric vehicle may travel approximately 200 miles or more without recharging. However, it should be noted that it is also contemplated that the electric vehicle based on the present invention can travel well over 200 miles without recharging. It is also contemplated in one embodiment that the electric vehicle using the energy storage system 12N of the present invention will be capable of accelerating from zero to sixty miles per hour in approximately four seconds.

The present invention may use batteries or cells made of lithium-ion cells 18N. In particular, one embodiment uses Commodity 18650 form factor lithium-ion cells 18N for the electric vehicle. The battery pack 12N in the present invention stores the chemical energy equivalent of approxi-
ately two gallons of gasoline. The battery pack 12N operates at a nominal 375 volts and delivers approximately 240 horsepower to the motor. This energy and power capability of the battery pack 12N may allow for the battery pack design and architecture to have many features that ensure the safety of the vehicle and its occupants during use of the electric vehicle. It should be noted that the lithium-ion cells 18N are rechargeable such that after recharging, the batteries will be able to provide traction power for the vehicle based on a fully recharged and capable battery. The energy storage system 12N in one contemplated embodiment comprises 6,831 individual lithium-ion 18650 cells 18N that will allow for it to achieve the drive power and range necessary for the vehicle. These cells 18N are electrically connected in parallel groups of sixty nine cells 18N wherein each of these groups of sixty nine cells 18N constitutes an electrical module called a brick.

[0402] The bricks are then connected in series within individual battery modules in the energy storage system called sheets 14N. Each sheet or battery module 14N is a single mechanical assembly and consists of nine bricks electrically connected in series. It should be noted that it is contemplated that the sheets 14N may be the smallest replacement unit within the energy storage system 12N and that each sheet 14N generally has a nominal voltage of approximately thirty five volts DC. Furthermore, each of these sheets 14N contain a mechanical mounting system, battery monitoring hardware electronics, and a thermal management system or cooling system according to the present invention as well as various safety systems to ensure proper protection for the vehicle and occupants of such vehicle. In the embodiment contemplated, eleven sheets 14N may be used in total to bring approximately 375 nominal volts DC to the energy storage system for use in the electric vehicle. Each of these sheets 14N will be rigidly mounted within an ESS enclosure 20N and electrically connected to one another in series. It should be noted that the ESS 12N contemplated and shown in the present invention may be adjusted by either increasing or decreasing the number of sheets 14N and/or boards within the ESS 12N. The energy storage system 12N may also include a battery monitor board 22N, wherein the battery monitor board 22N is associated with each sheet 14N of the energy storage system. The battery monitor board 22N monitors the voltage levels, temperatures and other parameters of all of the bricks within each sheet 14N.

[0403] Due to the high power output of the energy storage system 12N the individual cells 18N that comprise the ESS 12N must be thermally managed. This arrangement will increase and maximize the longevity of the energy storage system 12N. The cells 18N within the ESS 12N of the present invention may exhibit positive feedback thermal characteristics above a certain temperature which may result in failure of the individual cells 18N and the entire energy storage system. The methodology and mode of which this failure may depend has many factors but it is critical that these factors be monitored at all times during use of the battery pack 12N within the electric vehicle of the present invention. There is always the potential for propagation of an individual cell 18N that has overheated into nearby and adjacent cells 18N such that the energy storage system 12N must be closely monitored and controlled to prevent such thermal runaway of any single cell 18N, prevent thermal runaway of the cells 18N adjacent to either radially, axially or near by such that a cell 18N that has gone into thermal runaway or propagation may be slowed such that the rate of propagation to other cells 18N within the energy storage system 12N may be completely stopped or slowed such that destruction of the energy storage system 12N and associated cells 18N will not occur. It should be noted that all elements within the energy storage system 12N of the present invention have been designed to remove heat, redistribute heat from within the mass of the energy storage system 12N in order to achieve the prevention or slowing down of the rate of propagation of an overheated cell 18N within the energy storage system 12N.

[0404] It should be noted that the potential for thermal runaway and propagation of a cell 18N within the battery pack 12N of the present invention is a function that increases with the temperature of any of the individual cells 18N. The design of the present system 10N for mitigation of such propagation of thermal runaway events is generally a function of specific and general sources of heat that may raise the temperature of the cells 18N. Hence, the energy storage system 12N may have a variety of sensors for directly measuring components states, such as but not limited to temperature, voltage, and ambient conditions within the enclosure 20N and that these measurements are then used by hardware and software to make intelligent decisions to control the temperature of the energy storage system 12N so that it stays within an acceptable operating range. The energy storage system 12N may also function to take action in the event that one of the cells 18N or one portion of the energy storage system 12N is forced out of this desired operating temperature range to ensure that the ESS 12N stays within the desired operating range and that the cells 18N stay within their maximized operating range. Therefore, the energy storage system 12N includes the present invention of a system 10N of mitigating propagation of a thermal runaway event such that the system 10N of the present invention will control the temperature of the ESS 12N in both small scale and at the system level.

[0405] The energy storage system 12N has many possible sources of heat that may be a possible source of thermal runaway events within the energy storage system 12N. The source of heat may be internal and/or external heat sources when compared to the energy storage system 12N as a whole. One such internal heat source is internal cell 18N heating that occurs when one cell 18N has a high rate of discharge. This high rate of discharge may occur when the vehicle is under heavy acceleration and/or driving up a hill, etc. This type of internal heat is considered a part of normal operation of the vehicle, but is monitored for exceptional circumstances that may occur during extremely hot weather or other predetermined or unforeseen circumstances. The heat produced by such high rate of discharge of a cell 18N is generally a function of electric current and the cells internal resistance. Furthermore, a short circuit that is internal to the energy storage system 12N may also cause the cells 18N to heat up when the cells 18N experience a high rate of discharge. The short circuit generally is not part of the normal operation. It should be noted that every cell 18N in the energy storage system 12N is electrically connected by a fuse on both sides of the cell 18N wherein when the current for an individual cell 18N exceeds the fuse current the connection is broken and the circuit is stopped or opened. However, because the short circuit may be internal to the cell 18N, the cell 18N may continue to heat into thermal runaway and possibly propagate to adjacent cells 18N there around. It should be noted that the fuses current rating is dependent on the pack design in that the rating is above peak operating currents but significantly below the current of a short circuit scenario. The cells 18N
may also heat as a result of high voltage. The cells 18N generally are more sensitive to high temperatures when the cell voltage is high. This volatility is dependent on cell chemistry and varies among the different types of cells contemplated for use. The cells 18N in the energy storage system 12N could be overheated by the vehicles battery charging system (EVSE) or by the regenerative braking found in the electric vehicle of the present invention. It should also be noted that cells 18N may have suffered internal damage and as such may produce heat from internal chemical reactions. This damage may be caused by impact, crushing or heating to temperatures above the thermal runaway threshold of the individual cells 18N.

[0406] A high resistant electrical connection may also produce heat by dissipating the energy that passes through it, by proximity this may also heat a nearby cell 18N thus leading to thermal runaway and propagation of such overheated cells. The high resistance connection may be either internal/external to an individual cell 18N. It should further be noted that external arcing may occur anywhere within the energy storage system 12N and may produce intense heat in the path of the arc. This arcing could happen if two sheets 14N are short circuited in a crash or during any other known arcing phenomenon. It should also be noted that the cells 18N generally have a target operating temperature of approximately 25°C. It should be noted that this temperature reading depends on the system design and chemistry involved in the cells within the electric vehicle. Therefore, any known target operating temperature of anywhere between between 50°C and 200°C is contemplated for the present invention. When the external environment of the energy storage system 12N and associated battery pack and cells exceeds this temperature the energy storage system 12N must actively remove this heat from the system 12N to maintain safe and efficient operating temperatures. It is also contemplated that added heat to the ESS 12N may result from a number of unpredicted circumstances and events such as but not limited to a house fire, catastrophic accident, natural disasters and the like.

[0407] Therefore, as the system 10N monitors and looks for sources of heat within the ESS 12N, the ESS 12N also operates to control the temperature of its system. This temperature control is synchronous with propagation control since the high temperature that enables and sustains a thermal runaway event within a multi-cell battery pack 12N cannot occur if the temperature is properly controlled within the ESS 12N. Therefore, the management of heat and heat transfer also may play a role along with cooling and coolant transfer within the system 10N of mitigation of a thermal runaway event of the present invention.

[0408] Generally, the first level of temperature control of the mitigation system 10N of the present invention is that the ESS 12N may provide thermal mass in strategic locations and quantities to thermally balance the system 12N and mitigate the occurrence of extreme localized temperatures which may cause a cell 18N thermal runaway within the ESS 12N. The ESS 12N has three primary sources of thermal mass for the distinct purpose of distributing heat in the area of the cells 18N within each of the sheets 14N of the ESS 12N. One such source is a potting compound 24N which will hold the cells 18N in place with the electrically insulating and thermally conductive potting compound 24N. In one contemplated embodiment this potting compound 24N may physically glue the cells 18N in place within each of the sheets 14N of the energy storage system 12N. Therefore, when heat is generated locally by an individual cell 18N or group of cells 18N within the energy storage system 12N, the potting compound 24N may act as a sink to distribute the heat throughout the entire sheet 14N within which the overheating cell 18N or cells 18N are located. It should be noted that the thermally conductive compound 24N may be used to fill the space between the cells 18N in the battery pack 12N. The efficacy of the heat distribution of the potting compound 24N is a function of the physical mass, the thermal mass and the thermal conductivity of the potting compound 24N. This principle will apply to the ESS 12N configuration with a different number of cells and that is described or disclosed herein.

[0409] Another source of temperature control will be the use of cooling tubes 26N within the energy storage system 12N. In one contemplated embodiment aluminum cooling tubes 26N are arranged into each of the sheets 14N with the potting compound 24N such that the cooling tubes 26N are adjacent to each and every cell 18N within each sheet 14N. It should be noted that aluminum is one of the contemplated materials for use as a cooling tube 26N, however any other known metal, ceramic, composite, plastic, natural material or the like may also be used for the cooling tubes 26N. In one contemplated embodiment the cooling tubes 26N may be glued into each sheet 14N with the potting compound 24N. The cooling tube 26N may be made out of different materials and have a variety of geometries to achieve the best thermal balance between the cells 18N wherein a material is chosen based on the combined effects of the thermal mass, thermal conductivity, manufacturability and electrically properties thereof. In the case of the electrically conductive aluminum cooling tube 26N the entire assembly is assembled to be electrically insulated from the cells 18N. Generally a coolant will be arranged within the inner bore of the coolant tube 26N of the present invention. One type of coolant that may be used for the present invention may include propylene glycol and/or ethylene glycol, which usually are mixed with 50% or more water in many applications. In the ESS 12N, the aluminum cooling tubes 26N may be filled with such coolant such that the coolant is generally connected to the cells 18N via the cooling tube 26N and the potting compound 24N. Thermal mass of the coolant is significant to the sheets 14N capacity to dissipate heat in the present invention of a mitigation of thermal runaway event thereof. A pending application Titled “Battery Pack Thermal Management System” filed Jul. 18, 2007 having application Ser. No. , which is hereby incorporated by reference.

[0410] The system of mitigation 10N also includes collector plates 28N arranged on each end of the cells 18N within the ESS 12N. The collector plates 28N which connect the cells 18N electrically also provide a secondary thermal sink for the ESS 12N. The collector plates 28N have substantial thermal mass but have a relatively weak thermal connection to the cells 18N. These plates 28N generally are made of a highly conductive material, such as copper and aluminum alloys and cover the top and bottom surface of each sheet 14N in the ESS 12N. These collector plates 28N may also reflect radiant heat within the energy storage system 12N. It should be noted that the collector plates 28N may be of any known size, thickness and shape, include orifices therein and may be made of any known material such as metal, ceramic, composite, or any known natural material or plastic.

[0411] The mitigation system 10N of the present invention has an active cooling system in the ESS 12N that includes the vehicles heating, ventilation and air conditioning system.
(HVAC) 30N that removes heat from the pumped coolant, which removes heat from the cells 18N of the ESS 12N over a temperature gradient between the cells 18N and the cooling tube 26N. By actively removing heat from the sheets 14N of cells 18N, the mitigation system 10N may protect the cells 18N from thermal runaway events and failures. It should be noted that the HVAC pump 30N generally provides coolant circulation and heat distribution to reduce gradients across the vehicles cooling system. The pumped coolant is distributed to the channels 32N in each of the cooling tubes 26N via a manifold of a thermal management system. The cooling tube 26N of the present invention may have multiple channels 32N with cross flowing coolant to keep the temperature uniform along the length of the cooling tube 26N thus keeping the temperature of the adjacent cells 18N uniform such that a zero gradient is formed. It should be noted that the cooling system may be turned on in all failure modes whenever twelve volts is available to operate the HVAC system 30N including times when power is drawn from an external source and not the battery pack or energy storage system 12N of the present invention or A/C motor of the vehicle. The coolant is pumped and cooled through a single HVAC unit 30N in one contemplated embodiment, however it is contemplated to use a dual HVAC unit system within the electric vehicle of the present invention. The coolant is distributed among the sheets 14N in the ESS 12N so as to provide even cooling to the entire system. The manifold is designed to equalize pressure drops and to maintain a counter flow of coolant through the sheets cooling tubes 26N.

[0412] It is also contemplated that when required, especially at low temperatures, the HVAC system 30N may be capable of adding heat to the energy storage system 12N through the same pathways that remove heat in the active cooling mode. This is essential for maintaining the integrity of the cells 18N during normal operation of the electric vehicle.

[0413] Passive thermal control is also part of the mitigation system 10N in that the cells 18N in the ESS 12N have a predetermined geometry. In one contemplated embodiment the geometry of the cells 18N is that of a cylindrical shape. This cylindrical shape allows for a predetermined packing efficiency such that the cells 18N may be packed such that they are touching on every face, thus enabling the battery packs 14N to be the smallest configuration possible. In the event that a single cell 18N in such a small configuration may enter into thermal runaway, the heat produced by that one overheated cell 18N may transfer to the adjacent cells 18N and raise their temperatures to a point of propagation of the thermal event throughout the entire battery pack and ESS 12N of the electric vehicle. Therefore, the cells 18N of the present invention are arranged in a predetermined array and space such that the geometry of concern is the closeness of the surrounding cells 18N in all dimensions relative to any single cell 18N within that same array. Therefore, from the perspective of such a single cell in thermal runaway the cells 18N would be ideally packed very far apart from each other so that any heat from such individual cell 18N in thermal runaway would not be able to be transferred to the other cells 18N within the energy storage system 13N. Thus, the combination of geometric spacing and thermal properties of the surrounding materials is engineered in the present invention to optimize for best propagation prevention, the lowest weight for the entire energy storage system 12N and the most reasonable and smallest packing efficiency for use in the electric vehicle.

Therefore, transverse packing of the cells 18N and the associated spacing is optimized in the present invention. This transverse packing may refer to the cells 18N as they are packed in one of the eleven sheets 14N in the energy storage system 12N. A thermally conductive potting compound 24N enables quicker heat distribution among the cells 18N so that the cells 18N can be closer together than if they were separated by air alone. The orientation of the cells 18N transversely with relation to one another as shown in FIG. 86. The cell 18N spacing also optimizes the axial packing such that the distance between the end of the cells 18N as the sheets are packed into the ESS 12N enclosure is optimized. In this case the cells 18N generally are effectively placed end to end throughout the energy storage system 12N. FIG. 87 shows the cells oriented axially relative to one another. This cell 18N spacing both axially and transversely would produce the most efficient packing of the cells being placed directly end to end. However, the actual spacing, i.e., the spacing between sheets within the energy storage system 12N is dependent on electrical isolation, protected layers needed in between such sheets 14N and the thermal properties of the separating media between the sheets 14N of the energy storage system 12N.

[0414] Temperature control is also afforded to the mitigation system 10N via high temperature barricades. These high temperature barricades generally are sheet insulators 32N made of materials that provide physical heat barriers to contain propagation between sheets 14N within the ESS 12N. One type of material generally is a plastic material, such as Nomex, however any other type of insulating material may also be used. Generally, the collector plates 28N also serve this function of creating a physical heat barrier between propagation between sheets 14N within the ESS 12N. In the event of a cell 18N in thermal runaway, flames may be ejected from the positive end of the cell 18N in thermal runaway, thus causing propagation to a neighboring cell 18N in another sheet 14N of the ESS 12N. These high temperature barricades such as the sheet insulators 32N and the collector plates 28N may provide a barricade to block this flame from affecting adjacent modules or sheets 14N within the energy storage system 12N. Furthermore, in the event of an internal failure such a barricade 32N may protect the external environment from internally generating more heat thus propagating the thermal runaway within the ESS 12N.

[0415] In the event thermal runaway does affect one cell 18N within the ESS 12N, heat and flames may be vented from the ESS enclosure 20N via a valve membrane or shunt 34N. The release of the heat that occurs when the cell 18N enters thermal runaway will keep the ESS 12N internal temperature from rising while also the evacuation of flammable fumes will reduce the risk of generating additional heat from the combustion of those fumes. It should also be noted that all potentially flammable substances within the ESS 12N may be made of self-extinguishing materials such that in the presence of high heat these materials will not release more heat from combustion thus propagating the thermal runaway event within the ESS 12N. The use of self-extinguishing materials will especially apply to plastics, rubber and fiber products found in insulators, connectors and coatings and other components within the energy storage system 12N.

[0416] The temperature control of the ESS 12N may occur in any or all of the above described temperature control methodologies or components may be activated by the vehicle management system 36N which is an onboard computer that monitors, controls and coordinates various systems in the
electric vehicle including but not limited to the power electronics module 38N, the energy storage system 12N, the HVAC 30N and the user interface. The power electronics module 38N is a sister module to the ESS 12N that may house a DC/AC inverter for the traction motor, an AC/DC rectifier for charging and the control PCB for drive and charge. The heating and ventilation and air conditioning unit 30N may receive high power voltage from the ESS 12N via a connector. Although there are no HVAC components 30N inside the ESS enclosure 20N, the HVAC controller 30N receives its high voltage from the energy storage system 12N. The mitigation system 10N also may include a battery monitor board 22N that is a voltage and temperature monitoring printed circuit board that is integrated into each sheet 14N of the ESS 12N. The system 10N may also include a battery safety monitor 40N that is a watch dog computer in the ESS 12N that will communicate with the vehicle management system 36N and take action due to faults of changing voltage, temperature and current conditions as well as disconnected outputs. The system 10N also may include an axially power supply 16N that provides twelve volt power to the vehicle, wherein the auxiliary power supply 16N is located inside the energy storage system 12N and connects to the rest of the vehicle through a twelve volt connector 42N. The vehicle also may have a controller area network bus 44N that uses communication protocol generally used by many in the auto industry. The protocol is intended for embedded systems and is designed for real time performance within the electric vehicle. It should further be noted that a clamp shell member may locate and encase all of the cells 18N in a sheet 14N and that two clamp shell members generally form one of the main structural components of one individual sheet 14N. Therefore, according to the present mitigation system 10N the active components of the propagation mitigation system depend on an affective measurement of the condition of the ESS 12N. These measurements are generally taken from sensors 46N that are arranged throughout the ESS 12N and which are read by internal computers such as but not limited to the BMB 22N, BSM 40N, VMS 36N and PEM 38N by proxy. Generally, the mitigation system 10N of the present invention may include an inertia switch 48N that is hard mounted to the ESS enclosure 20N. When the ESS 12N is subject to a physical shock above a predetermined rated threshold the switch 48N will open thus cutting power to the battery pack 12N. The system 10N may also include a roll over switch that will open the ESS contacts 50N when the battery pack 12N is turned upside down due to a vehicle collision or other unforeseen event.

[0417] A plurality of sensors 46N are arranged throughout the ESS 12N and include but are not limited to an immersion sensor 46N which is arranged over the low internal surfaces of the ESS enclosure 20N where fluids may collect thus sensing fluid collection therein. A humidity sensor 46N may be built directly on the BSM 40N to monitor the internal conditions of the ESS 12N. The humidity is an important factor in conjunction with the temperature measurement to determine the dew point of the environment so as to not induce condensation within the energy storage system 12N of the present invention. The mitigation system 10N also may include a smoke sensor 46N that detects combustion products that are released during a thermal runaway event. The placement of the smoke sensors within the ESS 12N may allow for the sensors to be sensitive enough to detect the runaway of a single cell 18N anywhere within the pack 12N in a matter of seconds or milliseconds. The mitigation system 10N also may include an organic vapor sensor that may be used in parallel with the smoke or carbon dioxide sensor to detect combustion products that are missed by other sensors within the ESS 12N. It is also contemplated to use the sensor for temperature sensitive compounds in order to detect temperature sensitive compounds that would create an organic vapor when a cell 18N is in thermal runaway. Heated components may be coated with the material that releases a known detectable gas, mist, smoke or the like when the temperature of the coating exceeds a predetermined or predefined safety threshold on the component on which the material is coated thereon.

[0418] Furthermore, each sheet 14N in the ESS 12N may contain a plurality of thermostats in one contemplated embodiment six thermostats may be attached directly to the cells 18N and are measured and monitored by the BMB 22N of each of the individual sheets 14N. These thermostats will be attached to specific cells 18N which represent the adjacent cells 18N in terms of temperature measurement. These represented cells 18N may be chosen based on their proximity of potential failure points and are distributed among different bricks within the pack. Furthermore, each of the sheets 14N is divided into groups of cells known as bricks wherein each of the bricks is wired in parallel. The bricks within a sheet are then connected in series. Each brick within a sheet is connected to the sheets BMB 22N to measure the bricks voltage. Also, the mitigating system 10N may include current sensors 46N at the pack and module levels that will provide information about the instantaneous electrical use of the overall system. Because internal heat generation is typically a function of the square of current draw, current sensors 46N are critical to the present invention for detecting problems that result in high temperatures.

[0419] It should also be noted that fuses 52N are arranged throughout the ESS 12N at the pack level, at the module level and twice at the cell level. These fuses 52N in theory are both sensors and actuators. They will break the connection upon sensing an over current condition. For protecting against over current situations the ESS 12N is again prevented from generating excess heat during unusual events for which the fuses 52N are designed to counteract.

[0420] Electronics within the ESS 12N may be programmed to take actions based on the conditions met by state of the ESS 12N defined by a single measurement or combination of measurements as described above. Some of these actions may be performed directly by the BMBs 22N at the sheet 14N level while others are made in the form of messages to the BSM 40N or VSM 36N which in turn take action via other components in the ESS 12N or vehicle to counteract such detected overheating of a cell 18N, ESS 12N or the like.

[0421] One such action on detection is a voltage balancing mechanism between cells 18N of the ESS 12N. Generally, cells 18N within a sheet 14N may discharge unevenly, making one brick have a different voltage from other bricks in the ESS 12N. The BMBs 22N will communicate this information over the CAN 44N network and constantly drain energy from the higher voltage bricks in the pack 12N to the much lower voltage bricks. This energy may be expelled as heat, or in a more complex system the low voltage bricks may effectively be charged internally and high voltage bricks are discharged to balance the voltage of the entire pack to a stable uniform level. Such voltage balancing occurs as the voltage is monitored over all of the cells continuously by the BSM 40N via the BMBs 22N. The charging and braking systems use the
BSMs 40N measurement to keep the cell 18N voltages in a safe and predetermined working range.

[0422] It should be noted that if any brick in the battery pack 12N is higher than a predefined voltage or if the overall voltage of the battery pack 12N is above or greater than another predefined voltage the BMIs 22N will send a message to the BSM 40N to open the contactors 50N of the battery pack 12N thus disabling any current from flowing into or out of the ESS 12N. Furthermore, the ESS 12N may open its contactors 50N if the battery pack or cell voltages fall below a predetermined low voltage value for the system. It should also be noted that the contactors 50N open if any measured temperature is over a predetermined value. The electronics may also analyze the temperatures of the array of thermistors to determine if there is likely a higher temperature cell nearby that is not directly measured. In this case it would also shut off the pack by opening the contactors 50N thus stopping a potential or actual thermal runaway event from propagating.

[0423] An under temperature shut off may also occur for the ESS 12N when the temperature of the ESS 12N or associated cells 18N falls below a predetermined lower threshold. The contactors 50N of the ESS 12N may also open and shut off the ESS 12N if the current draw from the pack exceeds a predetermined safety limit. This function is redundant with the fuse protection but also may be used in cases where any current is drawn while the ESS 12N is in an unexpected state.

[0424] It should also be noted that in some cases such as when the vehicle is parked or not operating under normal driving conditions the HVAC system 30N is then not expected to operate as it would under normal driving conditions. The electronics and the associated ESS software may turn on the HVAC pump 30N to distribute heat throughout the system if the temperatures are rising due to external effects. The pump may also be turned on if the smoke sensor is triggered thus distributing heat before a problem is detected by the temperature sensors or other sensors within the ESS enclosure 20N. The electronics of the mitigation system 10N also may send error messages to the vehicle management system 36N when an error occurs thus notifying the driver of such error. In the event of a serious error messages may also be sent to an external server to notify agencies and personnel of the vehicle manufacturer so problem solving and prevention of failures in the future may also occur.

[0425] The cells 18N of the ESS 12N may also include predetermined internal safety features such as a positive thermal coefficient fuse, wherein each cell 18N in the ESS 12N may contain a fuse that disconnects the circuit in the event that the temperature exceeds a safety threshold. This temperature threshold will correspond to an energy that is below the activation energy that would start an exothermic reaction within the cell 18N. This positive thermal coefficient fuse may act to prevent thermal runaway in individual cells 18N. Each cell 18N may also contain a current interruption device within the ESS 12N that would disconnect the circuit when the internal pressure of the cell 18N exceeds a safety threshold. Such pressure increases are likely when the cells are overheated or overcharged during operation.

[0426] It should be noted that other propagation controls are contemplated for use in the present invention. One such control may be the use of small orifices in the collector plates 28N to keep any flames from an overheating cell 18N from exiting and entering the area next to the cell 18N. Furthermore, wire bonds used to connect the cell 18N to the collector plates 28N may melt during thermal runaway which disarms the current path of the cells 18N in thermal runaway. It is also contemplated to use phase change materials in the potting compound to absorb energy from the heated cells and to even use cooling tubes that may include plastics that will melt at a predetermined temperature above a failure mode below total thermal runaway. The tube 26N will then leak where the plastic is and remove heat from nearby cells 18N by direct contact with the coolant. It is also contemplated to use a fan to cool and move the air within the ESS 12N and maintain a uniform temperature therein. It is also contemplated to use the HVAC pump 30N in an always on manner during charging, as generally most failures happen during charging of the ESS 12N. It is also contemplated to use fiberglass above the potting line to limit heat transfer to only conduction and limit areas to potting to restrict heat conduction to certain paths. It should be noted that the cooling pump 30N is a significant active safety mechanism in that it operates as long as there is twelve volts available. Furthermore, even without the heat removal of the HVAC system 30N, moving the fluid through the vehicle helps distribute the heat evenly within the system. It also should be noted that the battery pack 12N will not charge at temperatures below 0°C, though it will still allow the vehicle to drive in conditions as low as ~20°C. To preserve chemical integrity the cells 18N must be heated above approximately 0°C to 5°C before charging will begin, once the ESS 12N has fallen below 0°C.

[0427] Referring to the drawings, an electric vehicle communication interface 10P is disclosed. The electric vehicle communication interface 10P is for use in any type of vehicle including an automobile, boat, train, plane, or any other transportation vehicle. However, it is specifically designed for use in an all electric vehicle 12P. The all electric vehicle 12P will operate completely on battery power for all propulsion and other automotive related needs. The electric vehicle 12P of the present invention uses a battery pack made of sheets of cells of lithium ion batteries arranged in a predetermined pattern. This battery pack will allow for propulsion of the electric vehicle 12P some distance before recharge is necessary. It should also be noted that the electric vehicle communication interface 10P of the present invention may be used in any other type of automotive vehicle, such as internal combustion, hydrogen cell vehicle, hybrid vehicle, alternative fuel type vehicle, or any other type of propulsion system known for a vehicle. It should also be noted that the electric vehicle communication interface may be completely wireless or include hard wire portions for use in connecting components as described herein.

[0428] FIGS 90 and 91 show the electric vehicle communication interface 10P according to one contemplated embodiment of the present invention. It should be noted that other contemplated embodiments for the connections necessary for the electric vehicle communication interface 10P may be possible. The electric vehicle communication interface 10P generally includes a communication device 14P arranged and installed within the electric vehicle 12P. The communication device 14P may be installed in any predetermined position within the electric vehicle 12P and may also be incorporated into the computer controlling the vehicle internal network. However, the communication device 14P may also be a stand alone device depending on the device requirements and environment in which the electric vehicle 12P will be used. Generally, the communication device 14P is a communication chip which may use an 802.11 protocol,
cellular or other standard protocol which are all well known in the art. In one specific embodiment a communication chip 14P developed by CircumNav Network may be used for the communication device 14P of the present invention. The electric vehicle 12P uses a communication chip 14P that is capable of communicating via any known protocol such as TCP/IP, GPRS, or any other standard protocol. The communication chip 14P allows for communication with a network 16P that may be cellular, internet, satellite or any other type of network or with a wired or wireless access point 28P. After the initial communication with network 16P the methodology then sends a communication from the network 16P to a second network 18P or to the user or driver 20P of the vehicle, or to a utility company or the manufacturer of the electric vehicle communication hub or server 22P. The second network 18P may include a manufacturer server or utility company server or any other known type of network while the first network 16P may include any cell tower, computer network, satellite system or hard line such as a phone network or power line network. The user 20P will be capable of communicating with either the first network 16P, the second network 18P or directly with the vehicle 12P via any user interface device 24P. Contemplated user interface devices 24P may include but are not limited to mobile devices, such as cell phones, PDA’s, handheld devices, desktop computers, laptop computers or any other communication device that is capable of producing email, IM, or any other communication device that is well known in the art. Some of these communications between the user interface devices 24P and either the first and second network 16P, 18P or the vehicle 12P may be performed via the code division multiple access standards (CDMA), the time division multiple access standards (TDMA), the global system for mobile communication standards (GSM), 802.11, BlueTooth, ZigBee, powerline communications including but not limited to HomePlug or Lonworks, a proprietary or standard communications protocol overlaid on existing charging communications equipment, a standard protocol such as CAN implemented on a custom physical layer, or any other standard protocol that is known in both wireless and hardwired configurations, for communication between any of the known user interface devices 24P and the first and second network 16P, 18P or the electric vehicle 12P directly.

[0429] If the 802.11 standard is chosen for use in the electric vehicle 12P, then the user 20P of the vehicle may then need to install and use a wireless router or any other known wireless access point 28P to enable the router to accept login from the electric vehicle 12P to allow for communication between the user interface device 24P and the electric vehicle communication chip 14P which operates on the 802.11 standard. It should be noted that with the other standards or protocols contemplated for use, other specific needs such as wireless router, hardwired connections, or the like may be needed and are all contemplated for use if necessary depending on the design requirement of the electric vehicle communication interface 10P as used in the electric vehicle 12P.

[0430] The use of the communication chip 14P as described above in the electric vehicle 12P may allow for communication to the first network 16P to allow for the vehicle 12P to contact the user 20P via the user interface device 24P by any known mobile device or desktop, laptop, etc., via email, instant messaging or any other known communication protocol. Also, it should be noted that the user or driver 20P of the vehicle is also capable of communicating with the electric vehicle 12P from their portable device such as a cell phone, PDA, laptop, personal computer, server, any known text messaging device, or any other communication device either directly with the vehicle 12P or through the first and second networks 16P, 18P to the vehicle to program and send specific instructions to the electric vehicle 12P for controlling and monitoring the battery system 26P arranged within the electric vehicle 12P. This communication between the electric vehicle 12P and user 20P or user 20P and electric vehicle 12P enables a plurality of scenarios through which the communication will have specific functions with respect to the propulsion system and other internal components of the electric vehicle 12P. In one contemplated controlling methodology for the communication interface 10P, the user 20P may be capable of querying or monitoring the electric vehicle’s battery pack and cells 26P for its state of charge (SOC). This will allow the user 20P to determine if the battery 26P is capable of driving the distance the user 20P must travel, if the battery 26P has not been charging or if the battery 26P is charged to the level set by the user and capable of a maximum mileage trip based on the battery installed therein. Another contemplated methodology will have the electric vehicle 12P notifying the user or driver 20P that the battery 26P is fully charged and is ready for driving. Yet another methodology contemplated will have the vehicle 12P notifying the user or driver 20P that a problem occurred during charging of the battery 26P and that the maximum distance for travel for the electric vehicle 12P has been reduced or that the electric vehicle 12P needs immediate servicing and is not available for driving at the present time. Still yet another methodology contemplated for the electric vehicle communication interface 10P for the present invention will have the user or driver 20P of the electric vehicle requesting the electric vehicle 12P to initiate heating or cooling of the vehicle 12P along with initiate heating or cooling of the battery cells and associated battery pack 26P to prepare for driving of the electric vehicle 12P. This preparation may include adjusting the battery temperature based on the distance of the expected drive, the external temperature that the electric vehicle 12P will be used in, the weather in which the electric vehicle will be driven and/or any other parameters that effect the performance and durability of the battery 26P and hence the electric vehicle 12P in the driving environment. Still yet another methodology contemplated for use in the communication interface 10P of the present invention may have the user 20P capable of powering on and off in predetermined cycles and at predetermined times the charging of the battery 26P from a user interface device 24P. Furthermore, the user 20P may be capable of discharging the battery 26P into the electricity or electric grid of the locale in which the electric vehicle 12P is either charged or stored via a vehicle to grid application that will allow for communication between a local utility company server and the electric vehicle 12P, thus allowing for certain operations to be performed by the utility company and the user 20P on the electric vehicle 12P. Yet another use would be to alert the user or manufacturer that the battery 26P is falling below the minimum accepted storage levels (3.0V for example). Such discharge of the battery 26P may allow the user to plug in the vehicle or recharge the battery 26P by other means to preserve the battery 26P.

[0431] The vehicle to electricity grid applications and methodology may allow for the user 20P to either pre-register or associate with a local utility company or energy provider which will allow for the utility company to control the timing
of charging or discharging of the electric vehicle 12P. This will allow the utility company during periods of high power consumption to have the option of turning off the charging of the electric vehicle 12P to help reduce the load on the electric grid controlled by the utility company and to avoid the sometimes necessary rolling blackouts. This also may allow for charging the vehicle 12P during periods of low power consumption by having the utility company to turn the charging of the electric vehicle 12P back on thus reducing the overall cost of operating the electric vehicle 12P by allowing for charging of the vehicle during periods of low power consumption which may result in lower kilowatts changes to the user of the electric vehicle 12P. It should be noted that the user 20P through the electric vehicle communication interface 10P and associated methodologies and methods of having a preset operating command to automatically reject or accept such charging control or request from such for the utility company. This methodology would allow for the user 20P to override the utility company instruction of stopping charging because of high power consumption if the user 20P of the electric vehicle 12P needs the battery 26P charged at the current time in order to use the vehicle in the near future. It is contemplated that this type of mutual control between the utility company and the electric vehicle 12P may be executed via the internet using the 802.11 communication protocol or cell phone communication with the electric vehicle 12P by the user 20P or the utility company. It should also be noted that it is contemplated within this methodology that the utility company may also be capable of remotely querying and sampling the electric vehicles state of charge for the associated battery pack 26P and then send predetermined and specific instructions or requests to the electric vehicle and/or user to discharge electricity back into the grid via the vehicle to grid applications stored within the electric vehicle communication interface 10P. This will allow the user 20P to further reduce its cost by discharging electricity back into the electric grid of the utility company and hence receiving credits and the like.

The electric vehicle communication interface 10P also may include an in vehicle display 30P which may be any known display touch screen, screen, TV, tube or any other type of display device known. The dashboard display 30P may be arranged in any part of the vehicle 12P including but not limited to sun visors, heads up displays, anywhere in the instrument panel, anywhere in the seats, or any other position within the vehicle and it is even contemplated to have a touch screen on the outer surface of the vehicle. When the user or driver 20P of the electric vehicle 12P turns off the motor of the electric vehicle 12P, the user 20P may be prompted via the display device 30P in the vehicle 12P to choose one of a plurality of predetermined charging options for the electric vehicle battery pack 26P. It should be noted that the user 20P may also use a menu or voice controlled device that allows for selection of a next charge state at any time during use of the vehicle. In one contemplated embodiment there will be three separate charging options which will be displayed on the touch screen 30P display located in the vehicle’s interior compartment. These charging options may include a boost charge which in theory is a full charge to the battery 26P of the electric vehicle 12P. By selecting the boost charge, the user 20P will be able to have maximum driving range such that the next time the user drives the electric vehicle 12P they can travel the maximum distance capable from the electric vehicle, however the boost charge may effect the durability and battery life of the battery pack 26P in the electric vehicle 12P over time. The second charging option displayed to the user or driver 20P of the electric vehicle 12P will be the regular charge option. The regular charge option generally will deliver a constant current charge up to a predetermined set voltage. The predetermined set voltage will be determined based on the battery pack system 26P and the configuration of the battery pack therein. It should be noted that a taper charge will not be used during the regular charge, which will result in the battery 26P not being completely charged after the regular charge option is chosen by the user. However, the regular charge will benefit the driver/user 20P of the vehicle 12P by allowing a quicker charge of the battery 26P and prolong battery life of the battery pack 26P in the electric vehicle 12P. However, the driving range will be reduced by a predetermined amount when selecting the regular charge option. In one contemplated embodiment the driving range will be reduced by about 4 to 10%. However, the reductions may generally be anywhere from 2% to 30% depending on the design requirements and batteries therein. The third option for one contemplated embodiment for charging of the battery pack 26P of the electric vehicle 12P will be a storage charge. This will allow the user 20P of the vehicle that does not plan to use the vehicle on a regular basis to maximize the life of the battery pack 26P. Generally, the storage charge is approximately a 50 to 50% charge. However, it should be noted that a range of 10 to 70% charge may also be used depending on the design requirements and environment in which the electric vehicle will be used. The storage charge will allow for the maximum life and durability of the battery pack system 26P in the electric vehicle 12P.

The communication chip 14P using the GPRS, which is a general packet radio service protocol, 802.11 standard, TCP/IP or any other standard protocol may communicate with a vehicle management system 32P which is the onboard computer that monitors, controls and coordinates various systems in the electric vehicle 12P including the power electronics module 34P, the energy storage system 26P and the HVAC system along with the user interface 30P. The communication chip 14P may also communicate with the wireless access point 28P or the power electronics module 34P. The communication chip 14P may also communicate with the vehicle management system 32P via a CAN BUS or any
other known communication interface or path, includes the battery pack of the electric vehicle 12P which is used to provide the power necessary to propel the electric vehicle 12P without the need for an internal combustion engine. The power electronics module 34P which is also controlled by the vehicle management system 32P, will house a DC to AC inverter for a traction motor, a DC to DC rectifier for charging and the control PCB’s for drive and charge of the electric vehicle energy storage system. The power electronics module 34P may also be in communication with an electric vehicle service equipment module 36P via power line communication, CAN BUS or any other known communication method, which also may be in communication with the display device 30P of the electric vehicle 12P. This will allow for any messages to be communicated to the user of the vehicle via the display device 30P within the vehicle. These messages may include service, appointments, or other tips to improve the mileage and efficiency of the battery pack 26P within the electric vehicle 12P.

[0435] A further component of the methodology used in the electric vehicle communication interface 10P will allow for the electric vehicle 12P every time it comes into contact with the home network of the manufacturer of the electric vehicle 12P or any other open network that it will send a message automatically through the communication chip 14P and over any known protocol such as the 802.11 standard to the manufacturer server 22P which may be networked as described above. The server 22P may also be in communication with the display device 30P, the electric vehicle service equipment 36P, or the text message gateway 24P. The manufacturer may then be capable of forming a database 38P of the user data such that the data storage will be held separately on the manufacturer’s server and will allow for cycle count, temperature, and other necessary data to be stored and evaluated or monitored to ensure efficient operation of the battery pack system and energy storage system within the electric vehicle 12P. The manufacturer’s server 22P also may be capable of data analysis regarding the charging cycles of the battery, miles driven per charge, temperature of the batteries, and any other data that is relevant to the efficient operation of the electric vehicle 12P. Therefore, every time the electric vehicle 12P comes in contact with a home network or other open network as described above it will automatically send, via a network, data to the manufacturer’s server 22P from the vehicle 12P, battery pack and energy storage system 26P. It should be noted that the communication protocol methodology will give the user or driver 20P of the electric vehicle 12P the option of disabling the automatic messaging to the manufacturer’s server 22P via either the display touch screen or via programming by a user interface device 24P on the internet or the like. It is also contemplated that upon initial programming of the vehicle 12P the user 22P may be able to set a default for either enabling or disabling the automatic message function. It should also be noted that it is contemplated that the methodology will allow the user or driver of the vehicle to access this data from the manufacturer’s server 22P via a portable hand held device or personal computer if necessary. It should also be noted that the manufacturer may use this data to broadcast specific messages to the user or driver 20P through the onboard communication chip 14P or through a cellular connection which will allow for displaying on the dashboard touch screen device 30P. These messages that may be shown on the display 30P may include servicing re-
Electric vehicles (EVs) include vehicles that have one or more sources of stored energy designed to provide electrical energy to the vehicle, wherein the electrical energy is used to at least in part to provide some energy used to propel the vehicle’s motions. Electrical vehicles may include vehicles designed to carry passengers, to transport goods, or to provide specialty work capabilities. For example, electrical vehicles include passenger automobiles, trucks, and recreational watercrafts such as boats. In addition, electrical vehicles include specialty vehicles, such as fork trucks used to lift and move cargo, vehicles that incorporate conveyer belts to move objects, such as mobile conveyer belt vehicles used to load and unload cargo such as luggage from airplanes, and specialty equipment used in areas where exhaust flames from typical gasoline, diesel, or propane powered equipment may present hazards to personnel, such as in underground mining operations. In various instances, electrical vehicles are designed and intended to be operated on public highways as licensed automobiles, including both cars and trucks.

Generally, an electric vehicle includes some form of a device or devices capable of storing energy and that is operable to provide electrical power to the vehicle. The electrical power may be used to at least in part provide energy for propelling the vehicle’s motion. In some instances, the electrical power is used to provide the energy required for all of the vehicle’s motion, including propelling the vehicle. In many instances, the source of the stored energy is a rechargeable battery pack. In various embodiments, a rechargeable battery pack includes a plurality of individual rechargeable battery cells that are electrically coupled to provide a rechargeable battery pack.

Fig. 92 shows a vehicle system 100Q, according to various embodiments of the present subject matter. In various embodiments, the vehicle 102Q is an electric vehicle and includes a vehicle propulsion battery 104Q and at least one propulsion motor 106Q for converting battery energy into mechanical motion, such as rotary motion. The present subject matter includes examples in which the vehicle propulsion battery 104Q is a subcomponent of an energy storage system (“ESS”). An ESS includes various components associated with transmitting energy to and from the vehicle propulsion battery in various examples, including safety components, cooling components, heating components, rectifiers, etc. The inventors have contemplated several examples of ESS and the present subject matter should not be construed to be limited to the configurations disclosed herein, as other configurations of a vehicle propulsion battery and ancillary components are possible.

The battery includes a lithium ion battery in various examples. In some examples, the battery includes a plurality of lithium ion batteries coupled in parallel and/or series. Some examples include cylindrical lithium ion batteries. In some examples, the ESS includes one or more batteries compatible with the 18650 battery standard, but the present subject matter is not so limited. Some examples include approximately 2981 batteries which are interconnected. The vehicle propulsion battery 104Q, in some examples, provides approximately 390 volts.

Additionally illustrated is an energy converter 108Q. The energy converter 108Q is part of a system which converts energy from the vehicle propulsion battery 104Q into energy: the at least one propulsion motor 106Q. In some instances, the energy flow is from the at least one propulsion motor 106Q to the vehicle propulsion battery 104Q. As such, in some examples, the vehicle propulsion battery 104Q transmits energy to the energy converter 108Q, which converts the energy into energy usable by the at least one propulsion motor 106Q to propel the electric vehicle. In additional examples, the at least one propulsion motor 106Q generates energy that is transmitted to the energy converter 108Q. In these examples, the energy converter 108Q converts the energy into energy which can be stored in the vehicle propulsion battery 104Q. In some examples, the energy converter 108Q includes transistors. Some examples include one or more field effect transistors. Some examples include metal oxide semiconductor field effect transistors. As such, in various examples, the energy converter 108Q includes a switch bank which is configured to receive direct current (“DC”) power from the vehicle propulsion battery 104Q and to output three-phase alternating current (“AC”) to power the vehicle propulsion motor 106Q. In some examples, the energy converter 108Q is configured to convert a three phase output from the vehicle propulsion motor 106Q to DC power. In other examples, the energy converter 108Q converts power from the vehicle propulsion battery 104Q into energy usable by electrical loads other than the vehicle propulsion motor 106Q. Some of these examples switch energy from approximately 390 Volts to 14 Volts.

The propulsion motor 106Q is a three phase alternating current (“AC”) motor, in various examples. Some examples include a plurality of such motors. The present subject matter can optionally include a transmission 110Q in some examples. While some examples include a 2-speed transmission, other examples are contemplated. Manually clutched transmissions are contemplated, as are those with hydraulic, electric, or electrohydraulic clutch actuation. Some examples employ a dual-clutch system that, during shifting, phases from one clutch coupled to a first gear to another coupled to a second gear. Rotary motion is transmitted from the transmission 110Q to wheels 113Q via one or more axles 112Q, in various examples.

A vehicle management system 114Q is optionally provided which provides control for one or more of the vehicle propulsion battery 104Q and the energy converter 108Q. In some examples, the vehicle management system is coupled to a vehicle system which monitors safety (such as a crush sensor). In some examples the vehicle management system is coupled to one or more driver inputs (such as a speed adjuster, colloquially termed a throttle, although the present subject matter is not limited to examples having an actual throttle). The vehicle system is configured to control power to one or more of the vehicle propulsion battery 104Q and the energy converter 108Q, in various embodiments.

A charging station 118Q is provided to transmit energy with the vehicle propulsion battery 104Q, in various examples. In some examples, the charging station converts power from a single phase 110V AC power source into power storable by the vehicle propulsion battery 104Q. In additional examples, the charging station converts power from a 220V AC power source into power storable by the vehicle propulsion battery 104Q. The present subject matter is not limited to examples in which a converter for converting energy from an
external source to energy usable by the vehicle 102Q is located outside the vehicle 102Q, and other examples are contemplated.

[0447] In various embodiments, vehicle system 100Q includes a windshield 130Q and a passenger compartment 132Q. Passenger compartment 132Q includes one or more passenger seats 134Q. In various embodiments, a heater/ventilation/air-conditioning (HVAC) system 120Q is included in vehicle system 100Q to provide safety and comfort features for passengers (not shown in FIG. 92) within the passenger compartment 132Q. In various embodiments, HVAC system 120Q includes a fan 122Q and air ducts 124Q operable to circulate heated or cooled air into the passenger compartment 132Q. In various embodiments, HVAC system 120Q includes an electrically resistive heating element operable to heat air in the HVAC system 120Q when electrical power is provided to heating elements 126Q. The heated air can be circulated by fan 122Q in order to provide heat in the passenger compartment 132Q, and to provide safety functions, such as defrosting or de-fogging, of windshield 130Q.

[0448] In various embodiments, vehicle system 100Q includes a vehicle display system (VDS) 140Q. VDS 140Q is operable to display visual information about vehicle system 100Q, including information related to the state of the propulsion battery 104Q, including battery charge. In various embodiments, VDS 140Q allows one or more inputs to be made to vehicle system 100Q. Inputs can be made through any device associated with the VDS 140Q operable to allow inputs to VDS 140Q, including pushbuttons. In various embodiments, a display screen coupled to VDS 140Q is a touch screen that allows inputs to be made to VDS 140Q. In various embodiments, VDS 140Q allows inputs for making a selection of a charge level for the propulsion battery 104Q included in vehicle system 100Q related to one or more upcoming charge operations of the propulsion battery 104Q, or for a charging operation currently in progress.

[0449] In various embodiments, one or more banks of electrically resistive heating elements 136Q provide a heated seat for a passenger when electrical power is provided to the banks of heating elements 136Q. In various embodiments, either of heating element 126Q or heating elements 136Q, or both, are used as part of a charging circuit as a voltage divider when performing a charging operation on the vehicle propulsion battery 104Q, as further described herein.

[0450] FIG. 93A shows a functional block diagram of a charging system 200Q for a battery pack 252Q according to various embodiments of the present subject matter. In various embodiments, charging system 200Q includes an electric vehicle 250Q coupled to a charger station 210Q. Electric vehicle 250Q is not limited to any particular type of electric vehicle. In various embodiments, electric vehicle 250Q includes the vehicle 102Q as described with respect to FIG. 92. Charger station 210Q is not limited to any particular type of charger station. In various embodiments, charger station 210Q is charger station 300Q as described with respect to FIG. 94.

[0451] Referring again to FIG. 93A, charger station 210Q includes a charger 216Q coupled to line source 212Q through connection 214Q and coupled to the electric vehicle 250Q through connection 220Q. Electric vehicle 250Q includes an electric vehicle management (EVM) system 260Q coupled to a battery pack 252Q and a heating/cooling system 270Q. Heating/cooling system 270Q is mechanically coupled to battery pack 252Q in order to provide heating and cooling of battery pack 252Q, as further described herein. Heating/cooling system 270Q is electrically coupled to EVM system 260Q as further described herein.

[0452] In various embodiments, EVM system 260Q includes a motor control circuit 280Q coupled to a drive motor 286Q. In various embodiments, motor control circuit 280Q is operable to use power provided by battery pack 252Q to condition and control electrical power provided to drive motor 286Q. In various embodiments, drive motor 286Q is operable to propel electric vehicle 250Q. In various embodiments, motor control circuit 280Q and drive motor 286Q are only operable when electric vehicle 250Q is physically disconnected from charger station 210Q.

[0453] In various embodiments, charger station 210Q is detachably coupled to electric vehicle 250Q through connection 220Q. Detachably coupled refers to connection 220Q being operable to be physically connected and disconnected, and thus operable to connect and disconnect, charger station 210Q to and from electric vehicle 250Q. When physically connected to electric vehicle 250Q, charger station 210Q is operable to provide electrical power to electric vehicle 250Q over one or more interconnects 230Q to one or more interconnects 240Q, wherein interconnects 240Q are part of electric vehicle 250Q. In various embodiments, connection 230Q includes a ground connection 234Q coupled to a ground connection 244Q in electric vehicle 250Q. In various embodiments, connection 230Q includes a signal interconnect 232Q coupled to signal interconnect 242Q and coupled to charger control circuit 226Q in charger station 210Q. Signal interconnects 232Q and signal interconnect 242Q are operable to allow communication and control signals to be transferred back and forth between charger station 210Q and electric vehicle 250Q. Interconnects 230Q, 240Q, 232Q, 242Q, 234Q, and 244Q are not limited to any particular type of connections, and in various embodiments include any combinations of physical conductors, multi-conductor cables, bus lines, transmission lines, and wireless connections, operable to allow communication and control signals to be transferred in either direction, or both directions, between charger station 210Q and electric vehicle 250Q.

[0454] Connection 220Q is not limited to any particular type of connection. In various embodiments, connection 220Q includes a connector 236Q that is part of the charger station 210Q, and a connector 246Q that is part of the electric vehicle 250Q. Connectors 236Q and 246Q are detachably connectable to allow a connection to be made between interconnects 230Q and 240Q, and between interconnects 232Q and 242Q, and between ground interconnects 234Q and 244Q, as these interconnect are provided in connection 220Q. In various embodiments, connector 236Q and 246Q are standard pin and sleeve connectors designed to conform with some known standard type of connector.

[0455] In various embodiments, connector 236Q is a custom-designed connector operable to couple to connector 246Q wherein connector 246Q is a custom and unique design intended to allow coupling only with a connector having a design matching connector 236Q.

[0456] In various embodiments, connection 220Q is operable to couple charger station 210Q and electric vehicle 250Q in order to allow charging of battery pack 252Q, and is operable to allow physically disconnecting charger station 210Q.
from electric vehicle 250Q in order to allow electric vehicle 250Q to move to areas away from, and free from any physical connections with, charger station 210Q.

[0457] In various embodiments, charger 216Q includes one or more strain sensors 217Q coupled to the charger control circuit 226Q. In various embodiments, strain sensors 217Q are operable to detect a level of strain on connection 220Q, such as a pulling force on connection 220Q, and to provide a signal that strain exists on the connection 220Q, (or in some embodiments, to stop providing a signal indicating that no strain exists in connection 220Q) to charger control circuit 226Q. In various embodiments, charger control circuit 226Q is operable to remove power from connection 220Q in response to a signal from the strain sensors 217Q, or in various embodiments, to remove power in response to not receiving a signal for the strain sensors 217Q—as in a fail-safe mode of operation. In various embodiments, charger 216Q includes a plurality of indicators 227Q-A through 227Q-N operable to visually indicate various conditions associated with charging system 200Q, including but not limited to an optical indication that connection 220Q has received an excessive amount of strain resulting in a cable strain fault condition.

[0458] In various embodiments, connectors 236Q and 246Q include a mechanical, electrical, or electro/mechanical detect mechanism 235Q operable to prevent connectors 236Q and 246Q from being physically disconnected if power is present and is applied to connection 220Q through interconnect 230Q and 240Q.

[0459] In various embodiments, line source 212Q is coupled to charger 216Q and is operable to provide electrical power to charger 216Q for operations including charging operations of battery pack 252Q. Line source 212Q is not limited to providing any particular voltage or type of electrical power. In various embodiments, line source 212Q provides single phase electrical power. In various embodiments, line source 212Q provides multi-phase electrical power, including but not limited to 3-phase electrical power, including but not limited to “wye” and “delta” arrangements. In various embodiments, line source 212Q provides electrical power referenced to a ground level. Line source 212Q is not limited to a particular voltage level. In various embodiments, line source 212Q provides a voltage level at one of a commercially available electrical power supply voltage levels as provided by an electric utility company. In various embodiments, line source 212Q provides a single phase, 220 volt alternating current (AC) source of electrical power. Line source 212Q, connection 214Q, charger 216Q, and connection 220Q have conductors appropriately sized and constructed to carry the voltage and current levels used in the operations of the charger station 210Q and electric vehicle 250Q, including operations involving recharging of battery pack 252Q from line source 212Q through charger station 210Q.

[0460] Various embodiments of charger 216Q include one or more devices 218Q for control of the electrical power delivered from line source 212Q to electric vehicle 250Q through charger 216Q. In various embodiments, devices 218Q include one or more devices 221Q for limiting the maximum current provided from charger 216Q to connection 220Q. In various embodiments, devices 221Q are fuses. In various embodiments, devices 221Q include a circuit breaker. In various embodiments, devices 221Q include a ground fault interrupt circuit in combination with a circuit breaker, wherein the ground fault interrupt circuit is operable to open the circuit breaker in the event a ground fault is detected.

[0461] In various embodiments, charger 216Q includes switching circuit 219Q. Switching circuit 219Q is operable to connect and to disconnect the electrical power provided from line source 212Q from electric vehicle 250Q. In various embodiments, switching circuit 219Q includes a mechanical relay. In various embodiments, switching circuit 219Q includes solid state relays or other solid state switching devices. In various embodiments, charger control circuit 226Q is coupled to switching circuit 219Q, and is operable to control opening and closing of switching circuit 219Q. In various embodiments, charger control circuit 226Q provides a signal to cause switching circuit 219Q to couple the line source 212Q to connection 220Q, and when the signal is not present, switching circuit 219Q is operable to disconnect line source 212Q from connection 220Q. In various embodiments, charger control circuit 226Q will cause switching circuit 219Q to disconnect line source 212Q from connection 220Q when the status of strain sensors 217Q indicates a level of strain on connection 220Q above some given level, or when a signal from strain sensors 217Q is not being received at charger control circuit 226Q to indicate a safe condition with respect to the strain on connection 220Q.

[0462] In various embodiments, charger 216Q includes a manual switch 224Q. In various embodiments, manual switch 224Q is coupled to switching circuit 219Q and operable to allow connection and disconnection of line source 212Q from connection 220Q through the actuation of manual switch 224Q. In various embodiments, actuation of manual switch 224Q to an “OFF” position disconnects line source 212Q from connection 220Q regardless of any signals from charger control circuit 226Q. In various embodiments, manual switch 224Q must be actuated to an “ON” position in order for line source 212Q to be electrically coupled to connection 220Q. In various embodiments, manual switch 224Q must be in an “ON” position, and a control signal from charger control circuit 226Q must also be provided in order for line source 212Q to be electrically coupled to connection 220Q. In various embodiments, manual switch 224Q includes a “OFF” position that allows manual switch 224Q to be locked in the “OFF” position, using a locking device (not shown in FIG. 93A) such as but not limited to a padlock.

[0463] Connection 220Q is operable to couple electrical power from line source 212Q to EVM system 260Q. EVM system 260Q is operable to couple electrical power received through connection 220Q to battery pack 252Q for performing charging operations on battery pack 252Q. In various embodiments, EVM system 260Q receives electrical power from lines source 212Q, and uses charging control circuit 262Q to manipulate power supply 261Q to provide as an output from power supply 261Q a voltage source operable for use in recharging battery pack 252Q. Manipulation of the electrical power from line source 212Q by charging control circuit 262Q is not limited to any particular type or types of manipulation, and may include manipulation of the voltage level, providing current control, altering the number of phases, rectification of AC electrical power, filtering of the electrical power, and changing the phase relationships between phases of any power provided from line source 212Q through connection 220Q to power supply 261Q. Charge control circuit is not limited to any particular charger topology. Charger control circuit 262Q may include any charging
topology operable to perform the charging operation described herein, including by not limited to Boost, Buck, and flyback charger topologies.

[0464] In various embodiments, power supply 261Q is operable to provide a voltage source for charging operations of battery pack 252Q and to provide one or more other sources of electrical power at one or more different voltages for use in other functions requiring electrical power in electric vehicle 250Q. In various embodiments, power supply 261Q provide electrical power for powering sensors, such as sensors 251Q and 276Q, and for powering one or more devices including controls circuits and devices, such as control 275Q and pump 274Q, as shown in FIG. 93A.

[0465] In various embodiments, battery pack 252Q includes a plurality of battery cells 255Q. In various embodiments, sub-groups of battery cells 255Q are electrically coupled together form bricks of battery cells, and one or more bricks are electrically coupled together to form sheets of battery cells. In various embodiments, battery pack 252Q includes a plurality of sheets. Within battery pack 252Q, the plurality of battery cells are coupled so that each of a first terminal of each of battery cells 255Q is electrically coupled to a first output terminal 253Q of battery pack 252Q, and a each of a second terminal of each of battery cells 255Q is electrically coupled to a second output terminal 254Q of battery pack 252Q. Individual battery cells 255Q can be coupled within battery pack 252Q in various combinations of series and parallel connections, depending on the desired output voltage and desired current requirements of battery pack 252Q.

[0466] In various embodiments, battery pack 252Q is mechanically coupled to heating/cooling system 270Q. In various embodiments, heating/cooling system 270Q is operable to heat and to cool a fluid that is circulated through battery pack 252Q in order to control the temperature within battery pack 252Q. In various embodiments, battery pack 252Q includes a network of tubing 299Q in thermal contact with one or more of the plurality of battery cells 255Q. In various embodiments, tubing 299Q is in thermal contact with each of the plurality of battery cells 255Q within battery pack 252Q. Tubing 299Q is formed of a material, such as a metal, that allows thermal transmission between the battery cells 255Q and the tubing 299Q. When a fluid is circulated through tubing 299Q, the fluid is operable to conduct heat to or away from the plurality of battery cells 255Q, depending on the temperature of the fluid circulating in tubing 299Q. The fluid is not limited to any particular type of fluid, and may include any type of fluid operable to circulate through tubing 299Q and transfer heat to and away from battery cells 255Q. In various embodiments, the fluid has a low freezing temperature wherein the fluid consist of a water and glycol mixture similar to that used as an anti-freeze in a typical automobile radiator.

[0467] In various embodiments, heating/cooling system 270Q includes a reservoir 273Q for holding a quantity of fluid and coupled through tubes 271Q and 272Q to the one or more networks of tubing 299Q within battery pack 252Q. In various embodiments, heating/cooling system 270Q includes heater 277Q operable to heat the fluid circulated by pump 274Q through tubes 271Q, 272Q, and tubing 299Q. Heater 277Q is not limited to any particular type of heater. In various embodiments, heater 277Q is a resistive type heating element operable to produce heat when electrical energy is provided to heater 277Q through electrical connections 295Q and 296Q. Heater 277Q is not limited to being located in any particular location. Heater 277Q may be located in any location that allows heater 277Q to heat the fluid in heating/cooling system 270Q being circulated through tubing 299Q. In various embodiments, heater 277Q is located in reservoir 273Q. In various embodiments, heater 277Q is located in line in one of tubes 271Q, 272Q, and tubing 299Q.

[0468] In various embodiments, heating/cooling system 270Q includes a cooling system 278Q for cooling the temperature of the fluid in reservoir 273Q and circulating the fluid through tubing 299Q. The cooling system 278Q is not limited to any particular type of cooling system, and in some embodiments includes a compressor and an a separate refrigeration system for cooling the fluid.

[0469] In various embodiments, heating/cooling system includes sensors 276Q. Sensors 276Q are operable to sense one or more parameters associated with heating/cooling system 270Q, including a temperature of the fluid in reservoir 273Q, or the fluid temperature as it is circulated to or from battery pack 252Q, and a rate or a volume of flow of the fluid as it is circulated through battery pack 252Q. In various embodiments, one or more of sensors 276Q are operable to sense a temperature of heater 277Q. In some embodiments, the sensor is operable to provide an output signal to the EVM system 260Q indicating a temperature of heater 277Q. In various embodiments where the temperature of the heater 277Q is provided to EVM system 260Q, EVM system 260Q is operable to disconnect electrical power from heater 277Q if the temperature of heater 277Q exceeds a given temperature.

[0470] In various embodiments, charging of battery pack 252Q is only enabled when battery pack 252Q is within a given range of temperatures. In various embodiments, when battery pack 252Q is not within a temperature range designated as an allowable temperature for charging operations on battery pack 252Q, charging control circuit 262Q is operable to provide control 275Q with control signals in order to have heating/cooling system 270Q circulate heated or cooled fluid through tubing 299Q within battery pack 252Q in order to adjust the temperature of battery pack 252Q to a temperature that is acceptable for charging, or continuing with, a charging operation of battery pack 252Q. In various embodiments, sensors 251Q within battery pack 252Q are used to determine the temperature within battery pack 252Q.

[0471] In various embodiments, sensors 251Q are operable to sense other conditions within battery pack 252Q that determine whether or not a charging operation can be initiated or continued if charging operation is already in progress, on battery pack 252Q. In various embodiments, sensors 251Q determine a level of humidity within battery pack 252Q, and a dew point of ambient air in or surrounding the battery pack 252Q. In various embodiments, based in the temperature, humidity, and dew points sensed, a determination is made to operate heating/cooling system 270Q in order to change the temperature, and in some instances the humidity, within battery pack 252Q before a charging operation is initiated, or during the charging operation. In some instances, a thermal response in battery cells 255Q to the charging operation, which could lead to moisture condensation within battery pack 252Q, triggers heating/cooling system 270Q to make a temperature adjustment within battery pack 252Q, either before or during the charging operation, or both before and during the charging operation.

[0472] In various embodiments, sensors 251Q include smoke detectors operable to detect the presence of smoke
within battery pack 252Q. In various embodiments, detection of smoke within battery pack 252Q results in a signal being provided to charging control circuit 262Q operable to cause charging control circuit 262Q to terminate a charging operation of battery pack 252Q by disconnecting any voltage source providing a charge voltage to battery pack 252Q from line source 212Q. In various embodiments, one or more signals from sensors 251Q or 276Q, or a combination of signals from these sensors, are used to set fault conditions, or provide a status for various indications in system 200Q. By way of illustration, a signal from sensors 251Q indicating the detection of smoke maybe transmitted to charging station 310Q and results in one of indicators 227AQ-227NQ visually indicating a smoke detection fault. In various embodiments, the status signals are provided through interconnect 242Q and 242Q of connection 220Q.

[0473] In various embodiments, charging control circuit 262Q is operable to determine a voltage level provided from line source 212Q through connection 220Q. In various embodiments, the determined voltage level is a peak-to-peak voltage of a sinusoidal voltage waveform providing the electrical power from line source 212Q. In various embodiments, the determined voltage level is a peak voltage a sinusoidal voltage waveform providing the electrical power from line source 212Q. By way of illustration, for a line source including a single phase alternating current having a nominal voltage of approximately 220 volts, the power source would have a peak-to-peak voltage of approximately 311 volts and a peak voltage of half the peak-to-peak voltage, or approximately 155 volts. Based on the determined voltage level provided from line source 212Q, comparator circuit determines a line voltage offset value. The line voltage offset value can be either a higher or a lower value than the determined voltage level provided from line source 212Q, by adding an offset value to the determined voltage level from the line source. The offset value may be a negative value, a positive value, or zero. In instances where the offset value is negative, adding the offset value to the determined voltage level from the line source results in a line voltage offset value less than the determined voltage level from the line source. In instances where the offset value is positive, adding the offset value to the determined voltage level from the line source results in a line voltage offset value greater than the determined voltage level from the line source. In instances where the offset value is zero, adding the offset value to the determined voltage level from the line source results in a line voltage offset value being the same as the determined voltage value from the line source.

[0474] FIG. 97A shows diagrams 750Q, 751Q, and 752Q. Each of diagrams 750Q, 751Q, and 752Q illustrate a comparison of the determined voltage level from the line source 704Q to a line voltage offset value 706Q. In diagram 750Q, the offset value 708Q is negative, and when added to the voltage level 704Q results in a line voltage offset value 706Q that is less than the determined voltage level from the line source 704Q. In diagram 751Q, the offset value 708Q is positive, and when added to the voltage level 704Q results in a line voltage offset value 706Q that is greater than the determined voltage level from the line source 704Q. In diagram 752Q, the offset value 708Q is zero, and when added to the voltage level 704Q results in a line voltage offset value 706Q that is equal to the determined voltage level from the line source 704Q.

[0475] In various embodiments, charging control circuit 262Q is operable to determine a voltage level present between the first terminal 253Q and the second terminal 254Q of battery pack 252Q as provided by the battery cells 255Q within battery pack 252Q. In various embodiments, charging control circuit 262Q includes comparator circuit 263Q. Comparator circuit 263Q is operable to compare the voltage level determined from the line source 212Q and the voltage level provided across the terminals 253Q and 254Q of battery pack 252Q, and to provide an output signal if the voltage level at terminals 253Q and 254Q is less than the calculated value of the line voltage offset value. Referring again to FIG. 97A, in each of diagrams 750Q, 751Q, and 752Q, arrow 710Q represents values for the voltage level across terminals 253Q and 254Q that are less than the calculated line voltage offset value 706Q, and arrow 712Q represents values for the voltage level across terminals 253Q and 254Q that are equal to or greater than the calculated line voltage offset value 706Q. Upon initiation of a charging operation of battery pack 252Q, for any voltage levels across terminals 253Q and 254Q that falls within the range represented by arrow 710Q, comparator circuit 263Q is operable to provide an output signal indicating the heating element is to be included in the charging circuit when charging is initiated. In various embodiments, the heating element will remain in the charging circuit until comparator circuit 263Q has determined that the heating element is to be bypassed in the charging circuit, as described herein.

[0476] In various embodiments, during a charging operation in which the heating element is included in the charging circuit, comparator circuit 263Q is operable to compare the voltage level determined from the line source 212Q and the voltage level provided across the terminals 253Q and 254Q of battery pack 252Q, and to provide an output signal if the voltage level at terminals 253Q and 254Q is less than the calculated value of a bypass threshold value voltage offset value.

[0477] FIG. 97B shows diagrams 760Q, 761Q, and 762Q. Each of diagrams 760Q, 761Q, and 762Q illustrate a comparison of the determined voltage level from the line source 704Q to a line voltage offset value 706Q, and a calculated voltage level 806Q representing a bypass threshold value. In diagram 760Q, the offset value 708Q is negative, and when added to the voltage level 704Q results in a line voltage offset value 706Q that is less than the determined voltage level from the line source 704Q. Bypass threshold value 806Q is calculated by adding a value 808Q to the line voltage offset value 706Q. In diagram 761Q, the offset value 708Q is positive, and when added to the voltage level 704Q results in a line voltage offset value 706Q that is greater than the determined voltage level from the line source 704Q. Bypass threshold value 806Q is calculated by adding a value 808Q to the line voltage offset value 706Q. In diagram 762Q, the offset value 708Q is zero, and when added to the voltage level 704Q results in a line voltage offset value 706Q that is equal to the determined voltage level from the line source 704Q. Bypass threshold value 806Q is calculated by adding a value 808Q to the line voltage offset value 706Q.

[0478] Referring again to FIG. 97B, in each of diagrams 760Q, 761Q, and 762Q, arrow 810Q represents values for the voltage level across terminals 253Q and 254Q that are less than the bypass threshold value 806Q, and arrow 812Q represents values for the voltage level across terminals 253Q and 254Q that are equal to or greater than the bypass threshold value 806Q. During charging operation including the heating element, when the monitored voltage level across terminals 253Q and 254Q remains in the range of values for arrow
the heating element will remain in the charging circuit. For any of the voltage levels across terminals 253Q and 254Q represented by arrow 820Q, the heating elements will be bypassed in the charging circuit. In instances where the heating element is included in a charging circuit and the voltage level across terminals 253Q and 254Q increases from a range represented by arrow 810Q up to the bypass threshold value 808Q, charging control circuit 262Q is operable to bypass the heating element, and to continue charging the battery pack 252Q with the heating element bypassed, as represented by arrow 812Q, and as further described herein.

[0479] By providing a line voltage offset value at a first voltage level wherein the heating element is included in the charging circuit when the battery pack voltage is less than the line voltage offset value, and by providing a bypass threshold value at a second and higher voltage level from the line voltage offset value, the bypass threshold value being a level wherein the heating element is removed from the charging circuit, the charging circuit includes a hysteresis band to control when to use the heating element included in the charging circuit upon initiation of a charging operation can be removed from the charging circuit.

[0480] Upon initiation of a charging operation of battery pack 252Q, for any voltage levels across terminals 253Q and 254Q that falls within the range represented by arrow 710Q, comparator circuit 263Q is operable to output a output signal indicating the heating element is to be included in the charging circuit when charging is initiated. In various embodiments, the heating element will remain in the charging circuit until comparator circuit 263Q has determined that the heating element is to be bypassed in the charging circuit, as described herein.

[0481] In each of diagrams 760Q, 761Q, and 762Q, the bypass threshold value is higher than the line voltage offset value by a value range 808Q. Value range 808Q represents a hysteresis band.

[0482] In operation, charging control circuit 262Q receives the output signal from comparator circuit 263Q, and is operable to configure switching circuit 264Q so as to include a the heating element as a voltage divider in the charging circuit used in the charging operation of battery pack 252Q. Having a series heating element in the charging circuit provides a voltage divider circuit for reducing the voltage applied to battery pack 252Q by either dropping the line voltage provided to the inputs of the power supply providing the charging voltage, or by dropping the charging voltage provided by the power supply to the battery pack across the heating element. The voltage divider circuit, including the heating element, allows charging control circuit 262Q to properly control the charging current provided to battery pack 252Q when the difference between the determined voltage level of line source 212Q and the terminal voltage level present at battery pack 252Q exceeds the pre-determined difference threshold voltage level.

[0483] In various embodiments, the heating element used in the charging circuit is heater 277Q. In various embodiments, the heating element is any electrically resistive conductive path that is operable to be used in a voltage divider circuit in a charging operation. In various embodiments, the heating element is a heating element used to heat an air flow circulated in a passenger compartment of electric vehicle 250Q. In various embodiments, the heating element uses a resistive element used to provide heat for defrosting a windshield of electric vehicle 250Q. In various embodiments, an electric fan is used to circulate the air past the heating element whenever the resistive heating element is used in a series circuit in the charging operation. In various embodiments, the heating element used is one or more of the resistive heating elements used to heat the passenger seats of electrical vehicle 250Q.

[0484] In various embodiments, switching circuit 264Q is operable to provide a voltage source to terminals 253Q and 254Q that includes heater 277Q coupled in series with terminals 253Q and 254Q and coupled across the voltage source provided by charging control circuit 262Q. Switching circuit 264Q is also operable to bypass heater 277Q, and to couple the voltage source provided by charging control circuit 262Q to terminals 253Q and 254Q without including heater 277Q. When heater 277Q is included in series with the terminals of battery pack 252Q, heater 277Q provides a voltage divider circuit with battery pack 252Q, wherein a portion of the voltage provided by the voltage source is dropped across heater 277Q, and the remainder of the voltage provided by voltage source is applied across terminals 253Q and 254Q to charge the battery cells 255Q in battery pack 252Q. When heater 277Q is bypassed, the entire voltage, less any loss in the connections 292Q, and 293Q, is applied to terminals 253Q and 254Q for use in charging the battery cells 255Q within battery pack 252Q.

[0485] FIG. 93B shows a charging circuit 290Q according to various embodiments of the present subject matter. The same reference numbers are used in FIG. 93B to depict corresponding elements as depicted in FIG. 93A. FIG. 93B includes switching circuit 264Q, power supply 261Q, and battery pack 252Q. A first output of power supply 261Q is coupled to terminal 253Q of battery pack 252Q through connection 292Q, and a second output of power supply 261Q is coupled to terminal 254Q of battery pack 252Q through connection 293Q. Power supply 261Q is operable to provide a voltage source at its first and second outputs for use in charging battery pack 252Q. Power supply 261Q receives electrical power through connections 240Q and 240DQ, and is operable to use the received electrical power to provide the voltage source for charging battery pack 252Q. Connection 240Q and 240DQ are coupled to connection 240AQ and 240BQ respectively through switching circuit 264Q.

[0486] In various embodiments, interconnects 240AQ and 240BQ couple to interconnects 240Q of connection 220Q, and provide the electrical power from line source 212Q (as shown in FIG. 93A) to switching circuit 264Q. Switching circuit 264Q is operable to connect or disconnect electrical power provided at connections 240AQ and 240BQ to power supply 261Q, and to include or not include heater 277Q in the coupling between connections 240AQ, 240BQ, and power supply 261Q. As shown in FIG. 93B, connection 240AQ is coupled to switch 265AQ, and connection 240BQ is coupled to switch 265BQ. Switch 265AQ is coupled to node 268Q, which is coupled to both switch 266AQ and switch 267Q. Switch 267Q is coupled to node 269Q, which is coupled to switch 266BQ and connection 240CQ. When closed, switch 267Q electrically couples switch 265AQ to connection 240CQ.

[0487] Switch 266AQ is coupled to connection 295Q, and switch 266BQ is coupled to connection 296Q. Heater 277Q is coupled to switching circuit 264Q through connection 295Q, through switch 297Q, and connection 298Q at one end of
heater 277Q, and connection 296Q at second end of heater 277Q. The heating element in FIG. 93B is not limited to heater 277Q of FIG. 93A, and may include any heating element operable to provide a voltage divider in charging circuit 299Q. Charging control circuit 262Q is coupled to switching circuit 264Q, and is operable to control each of switches 265AQ and 265BQ, 266AQ and 266BQ, and 267Q included in switching circuit 264Q.

[0488] Charging control circuit 262Q is operable to control whether switches 265AQ and 265BQ are open or closed. In various embodiments, charging control circuit 262Q operates switches 265AQ and 265BQ together to either connect or to disconnect electrical power provided on connections 240AQ and 240BQ to power supply 261Q. In addition, charging control circuit 262Q is operable to control whether switches 266AQ, 266BQ and 267Q are open or closed in various combinations and at different times, in order to include heater 277Q in the charging circuit 290Q, to bypass heater 277Q, and to couple connections 240AQ and 240BQ to power supply 261Q without including heater 277Q.

[0489] In various embodiments, where heater 277Q is included in the charging circuit, charging control circuit 262Q will operate to close both switches 266AQ and 266BQ and to open switch 267Q. Under these conditions, node 268Q will be coupled to connection 295Q through switch 266AQ, and node 269Q will be coupled through switch 266BQ to node 269Q. In this configuration, when switches 265AQ and 265BQ are closed, heater 277Q will be coupled in series with the power supply 261Q with respect to the electrical power provided at connection 240AQ and 240BQ, forming a voltage divider circuit for electrical power provided to the inputs of power supply 26.

[0490] When charging of the battery pack 252Q is to occur with the heating element bypassed in the charging circuit, charging control circuit 262Q will operate to open both switches 266AQ and 266BQ and to close switch 267Q. Under these conditions, node 268Q will not be coupled to connection 295Q through switch 266AQ, and node 269Q will not be coupled through switch 266BQ to connection 296Q. Instead, node 268Q will be coupled through switch 267Q to node 269Q. In this configuration, when switches 265AQ and 265BQ are closed, heater 277Q will be bypassed, and connection 240AQ will be coupled directly through switch 265A to configuration with the heating element bypassed, and when switches 265AQ and 265BQ are closed, power supply 261Q will be provided approximately the same voltage as supplied to connection 240AQ and 240BQ.

[0491] In various embodiments, when a charging operation is underway including heater 277Q coupled in the charging circuit, and a determination is made to bypass heater 277Q, switches 265AQ and 265BQ are first actuated to open these switches so as to disconnect the power supply 261Q from the battery pack 252Q, then switches 266AQ, 266BQ, and 267Q are configured to bypass heater 277Q by opening switches 266AQ and 266BQ and closing switch 267Q. Once switches 266AQ, 266BQ and 267Q are set so as to bypass heater 277Q, switches 265AQ and 265BQ are then closed to re-connect power supply 261Q to battery pack 252Q, and heater 277Q is now bypassed in the charging circuit.

[0492] Charging control circuit 262Q is operable to include or bypass heater 277Q in a charging circuit based on output signals provided by comparator circuit 263Q, as described herein. By providing heater 277Q in series with the line voltage being supplied to power supply 261Q, the input voltage level applied to the inputs of power supply 261Q are reduced over the voltage levels present on connections 240AQ and 240BQ, and thus allows power supply 261Q to maintain proper current regulation for charging battery pack 252Q. In various embodiments, the voltage level of battery pack 252Q is increased through the charging process, the voltage divider provided by heater 277Q is no longer required, and heater 277Q is bypassed to allow the voltage level present on connectors 240AQ and 240BQ to be provided to the inputs of power supply 261Q. In various embodiments, charging control circuit 263Q is operable to regulate the voltage across the heater 277Q by controlling the current flow through heater 277Q. In various embodiments, the voltage drop across heater 277Q is approximately one half the voltage of the line source being provided to the powers supply 261Q. In various embodiments, when alternating current power is being provided from the line source power and the heater is included in the charging circuit, charger control circuit is operable to energize the charging circuit for one or more cycles of the alternating current power, and to disconnect the alternating current power from the charging circuit 262Q for one or more cycles of the alternating current power, repeating this pattern a plurality of times in order to regulate the temperature of heater 277Q. In embodiments where direct current power is being provided as the line source power and the heater 277Q is included in the charging circuit, the charger control circuit 262Q is operable to switch the direct current power on and off in order to regulate the temperature of heater 277Q.

[0493] In various embodiments, heater 277Q is protected from overheating conditions by switch 297Q, by sensor 256Q, or by a combination of both switch 297Q and sensor 256Q. In various embodiments, switch 297Q is a switch that is opened and closed depending on a temperature of the switch, such as but not limited to a bi-metallic type switch. In various embodiments, switch 297Q is operable to remain closed, and thus couple heater 277Q to connections 295Q and 296Q, when heater 277Q is below a certain temperature, and to open when a given temperature of heater 277Q is exceeded. Opening switch 297Q disconnects any electrical power from having a path through heater 277Q, and thus is operable to prevent an overheating condition at heater 277Q. In various embodiments, sensor 256Q is operable to sense a temperature at heater 277Q, and to provide a temperature signal related to the temperature of heater 277Q to charging control circuit 262Q through connection 257Q. In various embodiments, charging control circuit 262Q is operable to open switch 297Q based on a temperature signal from sensor 256Q, and thus to disconnect any electric power from having an electrical path through heater 277Q. In various embodiments, when switch 297Q is opened during a charging operation, charging control circuit 262Q is operable to detect that current is not being provided to power supply 261Q through connections 240BQ and 240DQ, and to generate a charging fault condition signal.

[0494] The configuration of switches as depicted in FIG. 93B is not intended to be limiting, and is intended to show one possible arrangement of switches that could be used in switching circuit 264Q to correspond with the switching functions as described herein. It would be understood that other arrangements of switches, including arrangements having a different number of switches as illustrated in FIG. 93B, could be used to perform the switching functions as described.
herein. Switches 265AQ, 265BQ, 266AQ, 266BQ and 267Q, or any switches that are included in switching circuit 264Q to perform the switching function described herein, are not limited to any particular type or types of switches. Any type switches, including but not limited to mechanical relays, solid state relays, and solid state devices such as switching transistors, may be used in various embodiments and in any combinations that provide the switching functions as described herein.

[0495] FIG. 93C shows a charging circuit 290AQ according to various embodiments of the present subject matter. The same reference numbers are used in FIG. 93B to depict corresponding elements as depicted in FIG. 93A. FIG. 93C includes power supply 261Q coupled to battery pack 252Q through switching circuit 264Q. Various embodiments of charging circuit 290AQ operate switching circuit 264Q as described above with respect to FIG. 93B, except that the switch circuit 264Q and heater 277Q are coupled to form a voltage divider circuit with the output voltage provided as an output from power supply 261Q. In FIG. 93C, when heater 277Q is electrically coupled into charging circuit 290AQ, the output voltage from power supply 261Q is divided between heater 277Q and the battery pack 252Q. When heater 277Q is bypassed in charging circuit 290AQ, the voltage output from power supply 261Q is applied to battery pack 252Q.

[0496] Referring to FIGS. 93A and 93B, and while a charging operation is being performed on the battery pack 252Q, having heater 277Q included in series with battery pack 252Q will produce some heat based on the amount of voltage across and the amount of current through heater 277Q. In various embodiments, heating/cooling system 270Q will function to control and prevent overheating of both heater 277Q and battery pack 252Q. In various embodiments, sensors 276Q will monitor the temperature of heater 277Q, or of the fluid circulating in the heating/cooling system, or both, and will determine if cooling needs to be applied. In various embodiments, control 275Q will turn on fluid circulation when heater 277Q is included in the charging circuit. If the temperature of the heater 277Q or of the fluid in the heating/cooling system 270Q exceeds a predetermined level, heating/cooling system 270Q is operable to cool the fluid to prevent overheating. In various embodiments, control 275Q is operable to provide a signal over connections 294Q to charging control circuit 262Q to indicate that the temperature of heater 277Q or of the fluid circulating in heating/cooling system cannot be maintained below a level deemed acceptable for battery recharging, and to remove the heater 277Q from the charging circuit. In such instances, if charging of the battery pack 252Q cannot be performed without the voltage drop provided by heater 277Q, the charging operation will be terminated until a temperate change at the battery pack 252Q allows initiation of the charging operation.

[0497] In various embodiments, sensors 251Q in battery pack 252Q monitor one or more conditions within battery pack 252Q, and provides output signals through connection 291Q to EVM system 260Q. In various embodiments, one or more of sensors 251Q provides a signal representative of one or more temperatures within battery pack 252Q. In various embodiments, EVM system 260Q determines that the temperature within one or more portions of battery pack 252Q exceeds a level deemed to be appropriate for a charging operation. In such instances, if the heater 277Q is included in the circuit being used to charge the battery pack, heater 277Q is removed from the charging circuit. The charging operation will only continue on the battery pack if charging control circuit determines that a charging operation of the battery pack 252Q can be performed without including heater 277Q in the charging circuit. In various embodiments, an alternative heating element can be used, wherein heater 277Q can be removed from the charging circuit, and a different heating element as described herein, such as a heating element associated with the HVAC system, is coupled in the charging circuit in order to continued with the recharging operations without further heating the battery pack 252Q.

[0498] In various embodiments, EVM system 260Q includes one or more current control mechanism to provide a voltage at a controlled level of current to the charging circuit 290Q and across first terminal 253Q and second terminal 254Q in order to perform the charging of battery pack 252Q with a controlled current.

[0499] FIG. 94 shows a charger station 300Q according to various embodiments of the present subject matter. Charger station 300Q is not limited to any particular type of charging station. In various embodiments, charger station 300Q is charger station 210Q as shown in FIG. 93A. Charger station 300Q includes an enclosure 302Q coupled to a line source 301Q through a connection 310Q. In various embodiments, enclosure 302Q includes a conduit for electrical conductors, and the electrical conductors to couple electrical power from the line source 301Q into enclosure 302Q. In various embodiments, enclosure 302Q is operable to be mounted on a wall or other surface of a building structure, and to couple to connection 310Q through an opening 312Q in a rear side of enclosure 302Q.

[0500] In various embodiments, charger station 300Q includes a power and control circuit 304Q within enclosure 302Q and a connection including cable 352Q exiting from enclosure 302Q and terminating in a connector 353Q. Charger station 300Q is operable to couple incoming electrical power received from line source 301Q through power and control circuit 304Q to cable 352Q so that the electrical power can be coupled to a plurality of terminals 355Q included in connector 353Q. Power and control circuit 304Q is operable to connect and to disconnect the electrical power received from line source 301Q to and from cable 352Q and connector 353Q. In various embodiments, enclosure 302Q includes a surface 320Q including an ON/OFF switch 308Q. ON/OFF switch 308Q is operable to control the coupling of electrical power from line source 301Q to cable 352Q. In various embodiments, when ON/OFF switch 308Q is in the “OFF” position, the path for electrical power from line source 301Q to cable 352Q is physically disconnected. In various embodiments, when ON/OFF switch 308Q is in the “ON” position, electrical power will be coupled from line source 301Q to cable 352Q only if all the other conditions in charger station 300Q allow such a coupling.

[0501] In various embodiments, enclosure 302Q includes a protective device, such as a circuit breaker 306Q, mounted on the surface 320Q. Circuit breaker 306Q is operable to disconnect an electrical path between the line source 301Q and cable 352Q when the circuit breaker 306Q is in the OFF position, and to reconnect the electrical path between line source 301Q and cable 352Q when the circuit breaker is in the ON position.

[0502] In various embodiments, cable 352Q, in addition to one or more conductors coupled to terminals 355Q and used to carry electrical power, includes one or more separate conductors to carry communication and control signals to and from power and control circuit 304Q over cable 352Q. In
various embodiments, the additional conductors carry communication and control signals received at and provided from power and control circuit 304Q. In various embodiments, the communication and control signals are used to determine a status for one or more indicators 322Q, 324Q, 326Q, 328Q, and 330Q included on surface 320Q. In various embodiments, indicators 322Q, 324Q, 326Q, 328Q, and 330Q are visual indicators, such as but not limited to indicator lamps or light emitting diodes. The type of information indicated by indicators 322Q, 324Q, 326Q, 328Q, and 330Q is not limited to any particular type of information, and in various embodiments, includes one or more of a “READY,” a “GROUND FAULT,” a “SMOKE DETECTED,” a “CABLE STRAIN,” and a “CHARGING FAULT” indication. In various embodiments, charger station 300Q includes a audio output device 332Q, such as but not limited to a speaker or a beeper, operable to provide one or more audio outputs for indicating information. In various embodiments, a reset switch 340Q is included on surface 320Q. In various embodiments, reset switch 340Q is a ground fault interrupt circuit operable to provide an indication that a ground fault has occurred, for instance by actuating the reset switch to a fault position, and to allow resetting of the ground fault by actuating reset switch 340Q. In various embodiments, reset switch 340Q provides a fault input to power and control circuit 304Q in order to generate a fault condition that removes any electrical power provided from line source 301Q from cable 352Q.

[0503] In various embodiments, charger station 300Q includes a holster 357Q operable for retaining connector 353Q so as to provide a place to physical hold connector 353Q when cable 352Q and connector 353Q are not physically coupled to an electric vehicle for which the charging station is designed to couple to during charging operations.

[0504] In various embodiments, cable 352Q exits enclosure 302Q through a device 350Q such as a cord grip, wherein device 350Q protects cable 352Q from cut or puncture damage from any edges of enclosure 302Q, and provides strain relief for cable 352Q against pulling or flexing forces applied to cable 352Q. In various embodiments, wire grip 351Q is included over cable 352Q and attached to device 350Q. Wire grip 351Q is operable to provide physical protection to cable 352Q and to provide further protection against pulling and flexing forces applied to cable 352Q. In various embodiments, a sensor 356Q is included in enclosure 302Q. Sensor 356Q is operable to sense a level of physical strain being applied to cable 352Q, and to provide a signal to power and control circuit 304Q, the signal including information related to the level of strain on cable 352Q. In various embodiments, based on the sensed physical strain placed on cable 352Q, power and control circuit 304Q is operable to disconnect the electrical path coupling line source 301Q with cable 352Q. This feature is a safety feature that aids in preventing electrical power from being applied to cable 352Q after cable 352Q may have been damaged as a result of the physical strain.

[0505] In various embodiments, connector 353Q includes one or more coupling mechanisms 354Q. Coupling mechanisms 354Q provide a mechanism for mechanically latching connector 353Q into any mating connector (not shown in FIG. 94). That connector 353Q is intended to couple to. In various embodiments, coupling mechanisms 354Q prevent connector 353Q from being physically disconnected from a mating connector by merely pulling on cable 352Q, and require some type of action be performed on coupling mechanisms 354Q in order to remove connector 353Q from a mating connector. In various embodiments, coupling mechanisms 354Q cannot be actuated if electrical power is provided to terminals 355Q, and requires the electrical power be removed from at least terminals 355Q in order to actuate coupling mechanisms 354Q and disconnecting connector 353Q from a mating connector.

[0506] FIG. 95A shows a graph 400Q including a voltage waveform 410Q and a voltage waveform 430Q according to various embodiments of the present subject matter. In various embodiments, voltage waveform 410Q is a voltage waveform of the electrical power received from a line source, such as line source 212Q in FIG. 93, or from line source 301Q in FIG. 94. In various embodiments, voltage waveform 410Q is the voltage waveform provided to a power supply such as power supply 261Q used in a charging operation when the heater is not included in the charging circuit, and waveform 430Q is the voltage waveform provided to a the power supply used in the charging operation when the heater is included in the charging circuit. In various embodiments, waveform 430Q is derived from voltage waveform 410Q by applying voltage waveform 410Q to a voltage divider circuit formed using a heating element and a power supply used to provide the charge voltage during a charging operation.

[0507] Referring again to FIG. 95A, graph 400Q includes a vertical axis 402Q depicting voltage, and a horizontal axis depicting time. Voltage waveform 410Q depicts a variation in voltage over time. Voltage waveform 430Q depicts a different variation in voltage over time. In various embodiments, voltage waveform 410Q is a sinusoidal waveform having a period 418Q. A period refers to the time period for the sinusoidal waveform to complete one cycle (360 degrees). In various embodiments, period 418Q is equal to the inverse of the frequency of the voltage waveform as provided in a commercially available electrical power source. In various embodiments, period 418Q is a time period representative of voltage waveform having a frequency of 60 hertz. In various embodiments, period 418Q varies for any particular portion of waveform 410Q based on a power factor correction (PFC) applied by the entity providing the commercially available electrical power from which voltage waveform 410Q is derived.

[0508] In various embodiments, waveform 410Q includes a peak-to-peak voltage level 412Q. In various embodiments, waveform 410Q includes voltage levels relative to a given voltage level represented by line 420Q. In various embodiments, line 420Q represents a voltage level of zero volts relative to a ground, and waveform 410Q oscillates above and below the voltage level represented by line 420Q. The voltage represented by voltage 414Q is referred to as a peak voltage for waveform 410Q. In various embodiments, line 422Q represents an equivalent direct current (DC) value for a sinusoidal voltage represented by waveform 410Q, often expressed as a root mean square (RMS) value of the peak voltage 414Q. The value of the voltage at line 422Q is sometimes referred to at the nominal voltage level for a waveform. Voltage level 414Q is determined to be a values of a different between a voltage level at line 422Q and a peak voltage level of voltage waveform 410Q. The value of the voltage at line 422Q is determined by dividing a value of voltage level 414Q by the square root of 2. In various embodiments, any one of the peak-to-peak voltages 412Q, peak voltage 414Q, and nominal voltage at line 422Q may be used as the determined voltage level for the line source provided to the comparator circuit in order to determine if a heating elements should be included in the charging circuit used during a charging opera-
tion. In various embodiments, a given waveform 410Q, different values for the pre-determined difference threshold to be compared to the battery pack voltage depending on which one of the peak-to-peak, peak, or nominal voltage levels is used as the determined voltage level for the line source.

[0509] In various embodiments, waveform 430Q has a same period 418Q, a same phase as waveform 410Q, and is references to a same voltage line 422Q as waveform 410Q, but has a smaller amplitude, wherein the peak-to-peak voltage 432Q of voltage waveform 430Q is less than the peak-to-peak voltage 422Q for waveform 410Q, and wherein a peak voltage 434Q for voltage waveform 430Q is less than the peak voltage 412Q for waveform 410Q. In various embodiments, voltage waveform 430Q is generated by providing voltage waveform 410Q to a charging circuit including the heater in the electrical path of the charging circuit, wherein the heater acts as a voltage divider to provide waveform 430Q at the inputs to a power supply used in charging a battery pack. In various embodiments, voltage waveforms 410Q and 430Q represent voltage waveforms for input electrical power provided at separate times to a power supply used to recharge a battery pack. Voltage waveform 410Q represent a voltage waveform for electrical power provided to the power supply when the heater is bypassed in the charging circuit, and voltage waveform 430Q represents a voltage waveform for electrical power provided to the power supply when the heater is electrically coupled in the charging circuit.

[0510] By proving a reduced amplitude voltage waveform to the power supply, the power supply is able to properly control the current used to charge the battery pack when the battery pack voltage level is low and the difference between the battery pack voltage and the peak-to-peak voltage of the line source used in the charging circuit exceeds a pre-determined value, such as the line voltage offset value, as described herein.

[0511] FIG. 95B shows a graph 450Q of a voltage level for a battery pack during a charging operation according to various embodiments of the present subject matter. Graph 450Q includes a vertical axis 452Q representing a voltage level of a rechargeable battery pack, and a horizontal axis 454Q representing time. In various embodiments, the voltage level depicted in graph 450Q is the voltage level the battery pack 10Q of FIG. 4 showing various embodiments, the voltage level depicted in graph 450Q is the voltage level of the battery pack 252Q of FIG. 93A.

[0512] Referring again to FIG. 95B, a voltage level 480Q is present at the battery pack during time period 460Q. At time 470Q, a charging operation of the battery pack is initiated. At time 470Q, a voltage level 480Q is compared to a line voltage offset value represented by line 498Q, and represents a determined voltage level for the line source of the electrical power to be used in charging the battery pack. Since voltage 480Q is less than the line voltage offset value, charging of the battery pack will be initiated at time 470Q to include using a heating element in series with the line source and a set of power inputs to the power supply generating the charging voltage in the charging operation.

[0513] During time period 462Q, the charging operation including coupling the heating element in series with the line source, and the voltage level present at the battery pack increases from voltage level 480Q to voltage level 481Q, as shown by upward slope 482Q. At time 472Q, the voltage present at the battery pack has reached voltage level 481Q, which is the bypass threshold value calculated based on the line voltage offset value of line 498Q.

[0514] During time period 464Q between time 472Q and time 474Q, charging of the battery pack is changed over so that the heating element is bypassed, and the line source is coupled directly to the power inputs of the power supply without having the heating element in series with the line source.

[0515] The bypassing of the heating element occurs during time period 464Q, beginning at time 472Q and ending at time 474Q. At time 474Q, charging of the battery pack continues with the heating element bypassed in the charging circuit. Time period 466Q includes a time period where charging operation continues with the heating element bypassed, charging the battery pack to a final charge voltage 488Q at time 478Q, as represented by slope 486Q. The charging operation is terminated at time 478Q. For some time after time 478Q, the battery pack remains at a voltage level 488Q.

[0516] A hysteresis band 492Q includes a voltage range starting at voltage level 498Q representing a calculated line voltage offset value, and extending to voltage level 481Q, representing a bypass threshold value calculated based on the voltage offset value. Hysteresis band 492Q represents a difference in a value for voltage level at the battery pack for which initiating a charging operation will include using the heater in the charging circuit, and the voltage level in the charging operation wherein the charging operation will switch over to charging with the heater bypassed.

[0517] The time periods illustrated in graph 450Q are not necessarily proportional, and not necessarily to the same scale. Time period 460Q represents any time period prior to the initiation of a charging operation. Time period 462Q is not limited by any particular time period. In various embodiments, time period 462Q is a time period of between 2 and 3 hours. Time period 464Q is not limited to any particular time period. In some embodiments, time period 464Q is approximate 5 seconds. In some embodiments, time period 464Q is less than one second. In some embodiments, time period 464Q is less than 150 milliseconds.

[0518] Time period 466Q is not limited to any particular time period. In various embodiments, time period 466Q is between 2 and 4 hours. In some embodiments, time periods 466Q is more than 4 hours. In some embodiments, time period 466Q is less than 2 hours.

[0519] Time period 466Q ends at time 478Q when the a voltage level 488Q is present at the battery pack. Voltage level 488Q is not limited to any particular voltage level. In various embodiments, voltage level 488Q is a predetermined voltage level associated with a particular charge level. In various embodiments, voltage level 488Q represents a battery voltage level present on the battery pack when the battery pack is charged to approximately an 80% charge level. In various embodiments, the 80% charge level represents a battery voltage present on the battery pack and provided by the battery pack of approximately 405 volts DC.

[0520] In various embodiments, voltage level 488Q represents a battery voltage level present at the battery pack when the battery is charged to approximately a 100% charge level. In various embodiments, the 100% charge level represents a voltage level present on the battery pack and provided by the battery pack of in a range of approximately 410-412 volts DC.

[0521] In various embodiments, a final voltage level to which the charging operation to charge the battery pack to is less than a voltage level wherein the battery pack can be
charged during a charging operation without using the heating element in the charging circuit. By way of illustration, a low level charge for a battery pack may be desirable as the final charge voltage for a battery pack when the battery pack is being stored, or when the when the vehicle in which the battery pack is installed is not going to be operated for some extended period of time. In such instances, a targeted voltage level for the battery pack at the conclusion of a charging operation may be low voltage level, such as a voltage level representative of a 50% charge level for the battery pack. The lower charge level may be referred to as a storage charge level.

[0522] In various embodiments, the storage charge level may be a voltage level that is below any volt level wherein the difference between the determined voltage for the line source voltage and the final charge level for the battery pack being charged to a storage charge level will always be greater than the pre-determined difference voltage level. In such instances, any charging of the battery pack up to the storage charge voltage level will be done by having the heating element included in the charging circuit. This is illustrated in graph 450Q as the time period between time 470Q and 479Q, wherein a charging operation is initiated at time 470Q including having the heating element included in the charging circuit. At time 479Q, the voltage level at the battery pack has reached the storage charge voltage level, but the voltage level has not yet reached voltage level 481Q. When charging a battery pack to the storage charge voltage level as illustrated in graph 450Q, the charging operation is terminated at time 479Q, wherein the entire charging operation has been performed with the heating element having been included in the charging circuit and without going through the switching operation to bypass the heating elements as shown for time period 464Q.

[0523] FIG. 96 shows a flowchart 500Q for one or more methods according to various embodiments of the present subject matter.

[0524] At block 510Q, method 500Q includes determining that a charge operation on a rechargeable battery pack is to be performed. In various embodiments, determining that a charge operation on a rechargeable battery pack is to be performed includes determining that the rechargeable battery pack is to be charged to one of a plurality of predetermined battery charge levels.

[0525] At block 520Q, method 500Q includes comparing a supply voltage to a battery voltage of the rechargeable battery pack to determine a value for a difference signal. In various embodiments, comparing a supply voltage to a battery voltage includes providing an output signal if the difference between the compared supply voltage and the battery voltage exceeds a pre-determined difference threshold value.

[0526] At block 530Q, method 500Q includes generating a charging voltage from the supply voltage. In various embodiments, generating a charging voltage from the supply voltage includes the supply voltage being an alternating current power source having a sinusoidal voltage waveform.

[0527] At block 540Q, method 500Q includes initiating charging of the rechargeable battery pack by coupling the charging voltage to the rechargeable battery pack. In various embodiments, block 540Q includes block 550Q if the difference between the compared supply voltage and the battery voltage exceeds the pre-determined voltage level, and includes block 560Q if the difference between the compared supply voltage and the battery voltages does not exceed the pre-determined voltage level. In various embodiments, initiating charging and charging of the rechargeable battery pack includes controlling a current provided during the charging both when the heating element is coupled between the voltage source and the rechargeable battery pack and when the heating element is bypassed.

[0528] At block 550Q, method 500Q includes coupling the charging voltage to the rechargeable battery pack including coupling a heating element between the charging voltage and the rechargeable battery pack when the value of the difference signal exceeds a predetermined voltage level.

[0529] At block 560Q, method 500Q includes comparing the supply voltage to the battery voltage while charging the rechargeable battery pack and having the heating element between the charging voltage and the rechargeable battery pack to determine the difference signal, and bypassing the heating element and continuing the charging when the difference signal is less than a predetermined bypass threshold level.

[0530] At block 570Q, method 500Q includes bypassing the heating element when the value of the difference signal does not exceed the predetermined voltage value, the heating element operable to heat a fluid circulated through the rechargeable battery pack.

[0531] At block 580Q method 500Q includes circulating the fluid through the rechargeable battery pack during the charging while the heating element is coupled between the charging voltage and the rechargeable battery pack. In various embodiments, block 570Q further includes monitoring a temperature of rechargeable battery pack, and cooling the fluid circulated through the rechargeable battery pack when the monitored temperature exceeds a predetermined temperature level.

[0532] At block 590Q, method 500Q includes terminating the charging of the rechargeable battery pack when the voltage of the battery pack reaches a pre-determined voltage charge level. In various embodiments, reaching the pre-determined voltage charged level and terminating the charging occurs when the charging includes charging with the heating elements coupled between the charging voltage and the rechargeable battery pack. In various embodiments, reaching the pre-determined voltage charged level and terminating the charging occurs when charging includes charging the rechargeable battery pack with the heating elements is bypassed.

[0533] Embodiments of systems, methods, and apparatus for a battery charger have been described herein. Various embodiments include an apparatus comprising a rechargeable battery pack installed in an electric vehicle, the rechargeable battery pack coupled to a power supply, the power supply operable to provide a charge voltage to perform charging operations on the battery pack, a heating element to heat a fluid to be circulated through the rechargeable battery pack, the fluid thermally coupled to battery cells within the rechargeable battery pack, a comparator circuit to compare a battery voltage of the rechargeable battery pack to a line source voltage coupled to inputs of the power supply, the comparator circuit operable to compare the battery voltage to the line source voltage and to provide an output signal when the battery voltage is less than a line voltage offset value, the line voltage offset value calculated based on a value added to a determined voltage level for the line source voltage, and a control circuit coupled to receive the output signal of the comparator, and when a charge operation of the rechargeable
battery pack is to be initiated, the control circuit is operable to couple the line source voltage to the power supply, wherein the control circuit is to couple the heating element in series between the line source voltage and the power supply when the comparator circuit is providing the output signal indicating that the battery voltage is less than the line voltage offset value, and to bypass the heating element if the comparator is not providing the output signal indicating that the battery voltage is less than the line voltage offset value.

Various embodiments include a method comprising determining that a charge operation on a rechargeable battery pack is to be performed, comparing a supply voltage to a battery voltage of the rechargeable battery pack to determine a line voltage offset value, generating a charging voltage from the supply voltage, and initiating charging of the rechargeable battery pack by coupling the charging voltage to the rechargeable battery pack, wherein coupling the charging voltage to the rechargeable battery pack includes coupling a heating element between the supply voltage and a set of power inputs to a power supply providing the charge voltage to the rechargeable battery pack when the battery voltage is less than a line voltage offset value, and bypassing the heating element when the battery voltage is not less than the line voltage offset value.

Various embodiments include a system comprising a vehicle including a rechargeable battery pack, the rechargeable battery pack to provide at least a portion of the power used to propel the vehicle, a heating element to heat a fluid to be circulated through the rechargeable battery pack, the fluid thermally coupled to battery cells within the rechargeable battery pack, a charger operable to couple to a line source of electrical power and to detachably coupled to the vehicle, the charger to provide electrical power from the line source for performing charging operations of the rechargeable battery pack, a comparator circuit to compare a battery voltage of the rechargeable battery pack to a line source voltage coupled to inputs of the power supply, the comparator circuit operable to compare the battery voltage to the line source voltage and to provide an output signal when the battery voltage is less than a line voltage offset value, the line voltage offset value calculated based on a value added to a determined voltage level for the line source voltage, and a control circuit coupled to receive the output signal of the comparator, and when a charge operation of the rechargeable battery pack is to be initiated, the control circuit is operable to couple the line source voltage to the power supply, wherein the control circuit is to couple the heating element in series between the line source voltage and the power supply when the comparator circuit is providing the output signal indicating that the battery voltage is less than the line voltage offset value, and to bypass the heating element if the comparator is not providing the output signal indicating that the battery voltage is less than the line voltage offset value.

In the following description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present invention. The following description of example embodiments is, therefore, not to be taken in a limited sense, and the scope of the present invention is defined by the appended claims.

**FIG. 98** shows a vehicle system 100R, according to one embodiment of the present subject matter. In various embodiments, the vehicle 102R is an electric vehicle and includes a vehicle propulsion battery 104R and at least one propulsion motor 106R for converting battery energy into mechanical motion, such as rotary motion. The present subject matter includes examples in which the vehicle propulsion battery 104R is a subcomponent of an energy storage system ("ESS"). An ESS includes various components associated with transmitting energy to and from the vehicle propulsion battery 104R in various examples, including safety components, cooling components, heating components, rectifiers, etc. The inventors have contemplated several examples of ESSs and the present subject matter should not be construed to be limited to the configurations disclosed herein, as other configurations of a vehicle propulsion battery 104R and ancillary components are possible.

The battery includes one or more lithium ion cells in various examples. In some examples, the battery 104R includes a plurality of lithium ion cells coupled in parallel and/or series. Some examples include cylindrical lithium ion cells. In certain examples, the battery 104R includes one or more cells compatible with the 18650 battery standard, but the present subject matter is not so limited. Some examples include a first plurality of cells connected in parallel to define a first brick of cells, and a second plurality of cells connected in parallel to define a second brick of cells, with the first brick and the second brick connected in series. Some examples connect 69 cells in parallel to define a brick. Battery voltage, and as such, brick voltage, often ranges from around 3.6 volts to about 4.2 volts in use. In part because the voltage of batteries ranges from cell to cell, some instances include voltage management systems to maintain a steady voltage. Some embodiments connect 9 bricks in series to define a sheet. Such a sheet has around 35 volts. Some instances connect 11 sheets in series to define the battery of the ESS. The ESS will deliver around 385 volts in various examples. As such, some examples include approximately 6,831 cells which are interconnected.

Additionally illustrated is an energy converter 108R. The energy converter 108R is part of a system which converts energy from the vehicle propulsion battery 104R into energy usable by the at least one propulsion motor 106R. In some examples, the battery 104R powers the motor 106R to propel the vehicle. In certain instances, the energy flow is from the at least one propulsion motor 106R to the vehicle propulsion battery 104R. This can happen during regenerative braking, for instance. As such, in some examples, the vehicle propulsion battery 104R transmits energy to the energy converter 108R, which converts the energy into energy usable by the at least one propulsion motor 106R to propel the electric vehicle. In additional examples, the at least one propulsion motor 106R generates energy that is transmitted to the energy converter 108R. In these examples, the energy converter 108R converts the energy into energy which can be stored in the vehicle propulsion battery 104R. In certain examples, the energy converter 108R includes transistors. Some examples include one or more field effect transistors. Some examples include metal oxide semiconductor field effect transistors. Some examples include one more insulated gate bipolar transistors. As such, in various
examples, the energy converter 108R includes a switch bank which is configured to receive direct current ("DC") power from the vehicle propulsion battery 104R and to output a three-phase alternating current ("AC") power to the vehicle propulsion motor 106R. In some examples, the energy converter 108R is configured to convert a three phase signal from the vehicle propulsion motor 106R to DC power to be stored in the vehicle propulsion battery 104R. Some examples of the energy converter 108R convert energy from the vehicle propulsion battery 104R into energy usable by electrical loads other than the vehicle propulsion motor 106R. Some of these examples switch energy from approximately 390 Volts to 14 Volts.

[0540] The propulsion motor 106R is a three phase alternating current ("AC") propulsion motor, in various examples. Some examples include a plurality of such motors. The present subject matter can optionally include a transmission or gearbox 110R in certain examples. While some examples include a 1-speed transmission, other examples are contemplated. Manually clutched transmissions are contemplated, as are those with hydraulic, electric, or electrohydraulic clutch actuation. Some examples employ a dual-clutch type, during shifting, phases from one clutch engaged to a first gear to another coupled to a second gear. Rotary motion is transmitted from the transmission 110R to wheels 112R via one or more axles 114R, in various examples.

[0541] A vehicle management system 116R is optionally provided which provides control for one or more of the vehicle propulsion battery 104R and the energy converter 108R. In certain examples, the vehicle management system 116R is coupled to vehicle system which monitors a safety system (such as a crash sensor). In some examples the vehicle management system 116R is coupled to one or more driver inputs (e.g., an accelerator). The vehicle management system 116R is configured to control power to one or more of the vehicle propulsion battery 104R and the energy converter 108R, in various embodiments.

[0542] External power 118R is provided to communicate energy to the vehicle propulsion battery 104R, in various examples. In various embodiments, external power 118R includes a charging station that is coupled to a municipal power grid. In certain examples, the charging station converts power from a 110V AC power source into DC power for energy storage by the vehicle propulsion battery 104R. In additional examples, the charging station converts power from a 120V AC power source into power storable by the vehicle propulsion battery 104R. Some embodiments include converting energy from the battery 104R into power usable by a municipal grid. The present subject matter is not limited to examples in which a converter for converting energy from an external source to energy usable by the vehicle 100R is located outside the vehicle 100R, and other examples are contemplated.

[0543] Some examples include a vehicle display system 126R. The vehicle display system 126R includes a visual indicator of system 100R information in some examples. In some embodiments, the vehicle display system 126R includes a monitor that includes information related to system 100R. Some instances include one or more lights.

[0544] FIGS. 99-101 is a partial perspective view of a clamshell, according to one embodiment. The embodiments illustrate a bottom clamshell 302R. In various embodiments, the bottom clamshell 302R defines at least a first 304R recess. In additional embodiments, the bottom clamshell defines a second bottom recess 306R.

[0545] Various embodiments include a first battery 308R. In various embodiments, the first battery 308R includes a first bottom portion 310R that is disposed in the first bottom recess 304R. The first battery is cylindrical in some embodiments. Some embodiments include jelly roll batteries. Other embodiments include prismatic batteries. Prismatic batteries that are cylindrical are contemplated. Prismatic batteries including irregular shapes are contemplated. Prismatic batteries that have a different shape in a bottom portion 310R than they do a top portion 312R are contemplated. Various embodiments include a second battery 314R. In certain examples, the second battery 314R includes a second bottom portion 316R disposed in the second bottom recess 306R.

[0546] Various embodiments include a top clamshell 318R. In various embodiments, one or both of the top 318R and bottom 302R clamshells include a non-chlorinated, nombrominated flame retardant polycarbonate acrylonitrile butadiene styrene plastic (PC/ABS). The top clamshell 318R is shown sandwiching the first battery 308R and the second battery 314R between a top surface of the bottom clamshell 320R and a bottom surface of the top clamshell 322R. In certain examples, the top clamshell 318R defines a first recess 324R. Embodiments are contemplated in which the top clamshell 318R is substantially planar. In various embodiments, a substantially planar clamshell has a uniform thickness and is plate shaped. Some embodiments of a substantially planar clamshell have a cup shape, as a cake pan might have. Other shapes are possible. In various embodiments, the bottom clamshell 302R is similarly planar, but the present subject matter extends to embodiments where the bottom clamshell 302R is not planar and is used with a planar top clamshell 318R.

[0547] In various embodiments, the top 318R and bottom 302R clamshells sandwich a plurality of elongate cylindrical batteries including the first battery 308R and the second battery 314R. In some of these embodiments, the each of the batteries is substantially parallel to the other. In some of these embodiments, each of the plurality of batteries is perpendicular to a planar top clamshell 318R. In some embodiments, each of the plurality of batteries is perpendicular to a planar bottom clamshell 302R. In some embodiments, each of the plurality of batteries is perpendicular to both a planar top clamshell 318R and a planar bottom clamshell 302R.

[0548] In various examples, the top clamshell 318R defines a second top recess 326R. In various embodiments, a top portion of the first battery 312R is disposed in the first top recess 324R. In additional embodiments, a second top portion 328R of the second battery 314R is disposed in the second top recess 326R.

[0549] Some embodiments include a fill port 332R extending from a top surface 330R of the top clamshell 318R through to the bottom surface 322R of the top clamshell 318R. In various embodiments, the fill port 332R includes a cylindrical void in the top clamshell 318R. Other shapes are possible. The size of the fill port 332R is shown to be of a first aspect ratio with respect to the first battery 308R, and other aspect ratios are possible. In other words, the fill port 332R is a needle sized fill port in the top clamshell 318R. In various embodiments, the fill port 332R is part of a passage in fluid communication with a space 334R between the first battery 308R and second battery 314R.

[0550] In various embodiments, a protrusion 336R is coupled to the top clamshell 318R. In some embodiments, the protrusion 336R is coupled to the top clamshell 318R, proxi-
mate to the fill port 332R. In various embodiments, the protrusion 336R extending into the space 334R. Embodiments are contemplated, including those illustrated in FIGS. 99-101, in which the protrusion 336R at least partially occludes a direct path 338R through the fill port 332R into the space 334R. The protrusion 336R is molded into the top clamshell 318R in some embodiments, but other constructions are possible.

[0551] Various embodiments include an adhesive 340R at least partially disposed in the space 334R. Less than 350 milliliters of adhesive per fill port is specified in some embodiments. Less than 300 milliliters of adhesive per fill port is specified in some embodiments. Some embodiments use 18650 sized batteries and specify 25 milliliters of adhesive per fill port. Other capacities are contemplated. The protrusion 336R, in some embodiments, is molded such that it abuts a battery. In some embodiments, the manufacturing tolerance that controls the proximity of the battery, such as battery 308R, to the protrusion 336R is selected such that an adhesive 340R disposed in the space 338R wicks along the battery, between the protrusion 336R and the non-protrusion portions of the top clamshell 318R. In some of these embodiments, the adhesive 340R has a viscosity of from 20 to 50 centipoise at 25 degrees Celsius. In some embodiments, an adhesive 340R is free to drain into the space 338R. In various embodiments, an adhesive 340R is selected so that it resists traveling to the surface 320R.

[0552] Various embodiments include a bottom adhesive 344R that at least partially occupies portions of the first 304R and second 306R recesses of the bottom clamshell 302R that are not filled by one of the first 308R and second 314R batteries. In some embodiments, the top adhesive 340R fills the space 334R partially, with the bottom adhesive 342R also filling the space, and with a void 342R in the space disposed between the bottom adhesive 340R and the top adhesive 340R. Embodiments including the void are contemplated, in part, to cut down on the total weight of the system 300R. Embodiments that do not include a void 342R are contemplated. Embodiments in that a single epoxy at least partially occupies the space 334R as a monolith are additionally contemplated.

[0553] Various adhesives are contemplated. Epoxies that are two part epoxies are contemplated. In various embodiments, one or both of the top 340R and bottom 344R adhesives are electrically insulative. In some embodiments, one or both of the top 340R and bottom adhesives 344R are thermally conductive. Embodiments using an adhesive including a thermal conductivity of around 0.18 Watts/meter degree Celsius are contemplated. Embodiments using an adhesive including a thermal conductivity of around 0.18 Watts/meter degree Celsius are contemplated. In some embodiments, a top adhesive 340R includes DP270 adhesive by 3M Company. In some embodiments, a bottom adhesive includes a thermally conductive potting adhesive. Some embodiments include a Styca 2850 KT adhesive manufactured by Emco and Cuimng Company. Some of these embodiments are catalyzed using a D41V compound. Other adhesives not listed herein expressly are also used in the present technology.

[0554] FIGS. 102-103 show a clamshell including a protrusion, according to one embodiment. FIG. 102 illustrates a partial perspective view of a clamshell 502R including a bottom surface 504R with a protrusion 506R, according to one embodiment. FIG. 103 is a cross section taken along line 6-6, according to one embodiment.

[0555] In various embodiments, the protrusion 506R includes a wrapping portion 508R that at least partially wraps around the top portion of a first battery. In various embodiments, the protrusion 506R defines a trough 510R extending between the first battery and the protrusion, the trough in fluid communication with the fill port 512R. Access ways 514R are provided to allow access to batteries, such as for interconnecting them, in some embodiments. In various embodiments, the trough 510R is sized to receive a specified amount of adhesive. Less than 350 milliliters is specified in some embodiments. Less than 300 milliliters is specified in some embodiments. Some embodiments use 18650 sized batteries and specify 25 milliliters. Other capacities are contemplated.

[0556] In some embodiments, the trough 510R is sized to encourage a specified fill rate such that adhesive wicks into the trough 510R and around a battery at a specified rate. In some embodiments, this rate is compatible with a specified setting time period, such that adhesive can be dispensed into the trough 510R at a specified rate and the adhesive can proceed to occupy at least some of the trough 510R and then set, adhering the protrusion to a battery. Various protrusions are contemplated, including those that are molded to the clamshell 502R, as well as those that are affixed to the clamshell 502R.

[0557] FIG. 104 is a process 700R according to one embodiment. At 702R, various embodiments include disposing a bottom portion of a first battery into a first bottom recess of a bottom clamshell. At 704R, various embodiments include disposing a bottom portion of a second battery into a second bottom recess of the bottom clamshell. At 706R, various embodiments include sandwiching the first and second batteries between the bottom clamshell and a top clamshell by aligning the top clamshell and the bottom clamshell such that a top portion of the first battery is disposed in a first top recess of the top clamshell; and a top portion of the second battery is disposed in a second top recess of the top clamshell. At 708R, various embodiments include disposing, along a vector, adhesive through a fill port in the top clamshell and into interstices defined by the top clamshell, the bottom clamshell, and the first and second batteries, the vector interrupted by a protrusion coupled to the top clamshell and extending into the interstices.

[0558] Optional methods are contemplated. Some methods include filling, with the adhesive, portions the first and second recesses of the top clamshell that are not filled by one of the first and second batteries. In some of these methods, the adhesive wicks into the interstices.

[0559] Some embodiments include positioning, along only a two dimensional plane, a nozzle to dispense the adhesive. Some of these embodiments include positioning the top and bottom clamshell such that the vector is in substantially parallel and directional alignment with an acceleration vector. Some embodiments are included in which the acceleration vector is gravity. Some embodiments include applying a first adhesive against gravity to a first internal (battery side) surface of a first clamshell (e.g., the bottom clamshell) through a fill port in the first clamshell. Some embodiments include flipping a clamshell assembly to apply a second adhesive against gravity to a second internal surface of the second clamshell through a second fill port. Automatic robotics are used in some embodiments. Other configurations are possible.
Bonding with adhesive a first clamshell and a second clamshell together with batteries provides a number of benefits. One benefit is that the structure is less bendable. Another benefit is that the structure lasts longer because it does not suffer from as much vibrational wear. A further benefit is better heat exchange, via adhesive, between batteries and other components in an assembly, such as a cooling system. Other benefits not listed herein expressly are also possible.

In the following description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present invention. The following description of example embodiments is, therefore, not to be taken in a limited sense, and the scope of the present invention is defined by the appended claims.

The present subject matter provides systems and methods to charge a battery of a vehicle in a way that is adaptive to context. For example, in some parts of the world, electricity is less expensive during certain time periods. For example, electricity can be less expensive during nighttime, when less energy is being consumed due to lower air conditioning rates. This is an example time period, and others are possible.

The present subject matter provides users with the ability to select schedules to charge their vehicle in light of such varying rates. For examples, a user can charge their car to a regular capacity (e.g., 80% of capacity) or a regular energy stored rate (percent of capacity needed to store a set amount of energy increases over time) during times when it is less expensive to purchase electricity. Users can optionally select to charge the car in excess of the regular amount, perhaps to augment available driving range, in certain examples. In some instances, a user can select to charge to a regular rate before they sleep, and can wake up and select to charge in addition to the regular range as they prepare for their day. These and other embodiments are discussed herein.

FIG. 105 shows a vehicle system 1008S according to one embodiment of the present subject matter. In various embodiments, the vehicle 1025S is an electric vehicle and includes a vehicle propulsion battery 1045S and at least one propulsion motor 106S for converting battery energy into mechanical motion, such as rotary motion. The present subject matter includes examples in which the vehicle propulsion battery 1045S is a subcomponent of an energy storage system ("ESS"). An ESS includes various components associated with transmitting energy to and from the vehicle propulsion battery 1045S in various examples, including safety components, cooling components, heating components, rectifiers, etc. The inventors have contemplated several examples of ESSs and the present subject matter should not be construed to be limited to the configurations disclosed herein, as other configurations of a vehicle propulsion battery 1045S and ancillary components are possible.

The battery includes one or more lithium ion cells in various examples. In some examples, the battery 1045S includes a plurality of lithium ion cells coupled in parallel and/or series. Some examples include cylindrical lithium ion cells. In certain examples, the battery 1045S includes one or more cells compatible with the 18650 battery standard, but the present subject matter is not so limited. Some examples include a first plurality of cells connected in parallel to define a first brick of cells, with a second plurality of cells connected in parallel to define a second brick of cells, with the first brick and the second brick connected in series. Some examples connect 69 cells in parallel to define a brick. Battery voltage, and as such, brick voltage, often ranges from around 3.6 volts to about 4.2 volts in use. In part because the voltage of batteries ranges from cell to cell, some instances include voltage management systems to maintain a steady voltage. Some embodiments connect 9 bricks in series to define a sheet. Such a sheet has around 35 volts. Some instances connect 11 sheets in series to define the battery of the ESS. The ESS will demonstrate around 385 volts in various examples. As such, some examples include approximately 6,831 cells which are interconnected.

Additionally illustrated is an energy converter 108S. The energy converter 108S is part of a system which converts energy from the vehicle propulsion battery 1045S into energy useable by the at least one propulsion motor 106S. In certain instances, the energy flow is from the at least one propulsion motor 106S to the vehicle propulsion battery 1045S. As such, in some examples, the vehicle propulsion battery 1045S transmits energy to the energy converter 108S, which converts the energy into energy usable by the at least one propulsion motor 106S to propel the electric vehicle. In additional examples, the at least one propulsion motor 106S generates energy that is transmitted to the energy converter 108S. In these examples, the energy converter 108S converts the energy into energy which can be stored in the vehicle propulsion battery 1045S. In certain examples, the energy converter 108S includes transistors. Some examples include one or more field effect transistors. Some examples include metal oxide semiconductor field effect transistors. Some examples include one more insulated gate bipolar transistors. As such, in various examples, the energy converter 108S includes a switch bank which is configured to receive a direct current ("DC") power signal from the vehicle propulsion battery 1045S and to output a three-phase alternating current ("AC") signal to power the vehicle propulsion motor 106S. In some examples, the energy converter 108S is configured to convert a three-phase signal from the vehicle propulsion motor 106S to DC power which is stored in the vehicle propulsion battery 1045S. Some examples of the energy converter 108S convert energy from the vehicle propulsion battery 1045S into energy usable by electrical loads other than the vehicle propulsion motor 106S. Some of these examples switch energy from approximately 390 Volts to 14 Volts.

The propulsion motor 106S is a three phase alternating current ("AC") propulsion motor, in various examples. Some examples include a plurality of such motors. The present subject matter can optionally include a transmission or gearbox 110S in certain examples. While some examples include a 1-speed transmission, other examples are contemplated. Manually clutched transmissions are contemplated, as are those with hydraulic, electric, or electrohydraulic clutch actuation. Some examples employ a dual-clutch system that, during shifting, phases from one clutch coupled to a first gear to another coupled to a second gear. Rotary motion is transmitted from the transmission 110S to wheels 112S via one or more axles 114S, in various examples.

A vehicle management system 116S is optionally provided which provides control for one or more of the
vehicle propulsion battery 104S and the energy converter 108S. In certain examples, the vehicle management system 116S is coupled to vehicle system which monitors a safety system (such as a crash sensor). In some examples the vehicle management system 116S is coupled to one or more driver inputs (e.g., an accelerator). The vehicle management system 116S is configured to control power to one or more of the vehicle propulsion battery 104S and the energy converter 108S, in various embodiments.

[0569] External power 118S is provided to communicate energy with the vehicle propulsion battery 104S, in various examples. In various embodiments, external power 118S includes a charging station that is coupled to a municipal power grid. In certain examples, the charging station converts power from a 110V AC power source into power storable by the vehicle propulsion battery 104S. In additional examples, the charging station converts power from a 120V AC power source into power storable by the vehicle propulsion battery 104S. Some embodiments include converting energy from the battery 104S into power usable by a municipal grid. The present subject matter is not limited to examples in which a converter for converting energy from an external source to energy usable by the vehicle 100S is located outside the vehicle 100S, and other examples are contemplated.

[0570] Some examples include a vehicle display system 126S. The vehicle display system 126S includes a visual indicator of system 100S information in some examples. In some embodiments, the vehicle display system 126S includes a monitor that includes information related to system 100S. Some instances include one or more lights. Some examples include one or more lights, and the vehicle display system 126S in these embodiments includes the illumination and brightness of these lights. The vehicle management system, in certain embodiments, coordinates the function of a charge state circuit 106S, and the charging coupler port 108S, as pictured in FIG. 105. In certain instances, the charge state circuit 106S, and the charging coupler port 108S are part of the vehicle management system 116S. In some of these instances, the lighting circuit 114S is part of the vehicle display system 126S. In certain examples, the illuminated indicator 116S of FIG. 105 is part of the vehicle display system 126S.

[0571] FIG. 106 is a diagram of an electrical vehicle charging system 202S, according to one embodiment. In various embodiments, the system includes an electric vehicle 204S and a battery 206S coupled to the electric vehicle to the electric vehicle 204S to propel the electric vehicle 204S. Electric vehicles contemplated by the present subject matter include ground based vehicles, as well as aircraft and aquatic vehicles.

[0572] The illustration includes a charging circuit 208S to charge the battery 206S. This can include an external charging station that converts power from a municipal power grid to power that can be stored in battery 206S. This can additionally include changing converter onboard the electric vehicle that can take energy from a generally available outlet of a municipal power grid (such as a National Electrical Manufacturers Association 5-15 outlet) and convert it to power storable in the battery 206S. Other configurations are possible.

[0573] Various examples include a charging cost circuit 212S to estimate a charging cost rate. In various embodiments, a charging cost rate is the instantaneous cost of energy transfer. Cost rate is in cost per energy transferred over time (e.g., $0.06 United States Dollars per kilowatt hour). The present subject matter is compatible with various ways of measuring how much energy is consumed and how quickly it is being consumed.

[0574] In various examples, the charging cost circuit 212S can control the charging circuit 208S and turn it on or off. In various embodiments, this includes interrupting a conductive path to the charging circuit 208S, such as by opening a switch. In additional instances, this includes communicating a charging state signal indicative of whether the charging circuit 208S should be active or inactive. For example, in certain examples, a field effect transistor switches activation power to the charging circuit 208S, and the charging cost circuit 212S controls the gate for the field effect transistor.

[0575] In some embodiments, the charging cost circuit 212S is part of a computer onboard a vehicle (e.g., the vehicle management system 116S of FIG. 105). In additional examples, the charging cost circuit 212S is part of a computer in a home or workplace that at least partially controls how the electric vehicle 204S is charged. Various embodiments include a timer circuit to provide a time signal to the charging cost circuit. The timer 210S can be integrated with an electronics module, such as an assembly including a printed circuit board, the timer, and the charging cost circuit.

[0576] In various examples, the charging cost circuit 212S is to turn on the charging circuit 208S during a first time period in which the charging cost rate is below a first threshold. In certain instances, the charging circuit 208S is turned on until the battery reaches a first energy stored level (e.g., a specified amp-hours amount, coulomb amount, etc.). In some optional embodiments, the charging cost circuit 212S turns on the charging circuit 208S during a second time period in which the charging cost rate is above the first threshold. This might be during the morning, after a power supplier has switched to a higher cost rate, but before a user begins to drive their electric vehicle.

[0577] In various examples, the system includes a cost estimator circuit to calculate total charging cost during the first period and the second period. For example, this circuit can estimate that it will cost $5.00 to charge an electric vehicle based on measured conditions and optionally learned conditions. In certain examples, an electric vehicle charging system monitors energy use patterns to estimate total charging cost. In additional embodiments, an electric vehicle charging system monitors energy use patterns to estimate total charging cost. Some of these examples include a trend circuit to record a plurality of charging stop times over a period of days, and to predict a predicted charging stop time based on the plurality of charging stop times. A charging stop time, in various embodiments, is the time of day when a user usually unplugs their electric vehicle. In many cases, this is right before the user engages their electric vehicle for a drive.

[0578] In some examples, the charging cost circuit 212S automatically selects the length of the second time period to achieve a reduced charging cost that is less than a total charging cost. For example, if an electric vehicle charging system estimates a total charging cost as set out above, it can monitor charging cost rates and adjust time spent charging during a less expensive rate and time spend charging during a more expensive rate, such that the day’s predicted cost of charging is less than the total charging cost that was estimated.

[0579] If desired, certain embodiments include a user controllable interface connected to the charging cost circuit 212S.
such that the user can input a threshold for what is a less expensive charging cost rate and what is a more expensive charging cost rate. For example, in certain embodiments, a user could specify to charge only when below a certain threshold by interacting with a computer (e.g., a vehicle computer or a home computer).

In some examples, the present system is also aware of how calendar life is being impacted by charging behaviors. This can be studied using monitored variables (e.g., by performing a load test) or by monitoring charging behavior over time (e.g., counting the number of cycles and monitoring cycle parameters such as current rate and time duration). The system can prioritize whether charging is selected to improve calendar life or reduce cost. For example, some instance charge a battery to a regular energy stored level, such as 80% of full stored energy, preferentially to improve calendar life, as certain battery chemistries, such as lithium ion, last longer if they are charged as such. Some examples will not charge above a regular energy stored level unless instructed to. Instruction can be in the form of an indicator, such as a signal from a computer that automatically provides the signal based on an analysis, or it can be provided based on a manual interaction with a user. For example, an electric vehicle can be adjusted so that it is always in "regular mode" in which it charges to 80% of full stored energy for most of its life, and is only charged to "boost mode" (e.g., 90% of full stored energy level) when a user or other source instructs it to do so.

As such, in certain examples, the charging cost circuit 2125 is to turn on the charging circuit until the battery reaches a second energy stored level. The second energy stored level can be at a first energy stored level and a full energy stored level, or it can be at a full energy stored level. The present subject matter includes embodiments in which that charge is held at the second energy stored level for a period of time. For instance, if a first time period is specified in which a first energy stored level can be reached, and a second time period is specified in which a second energy stored level can be reached, the present system can reach the first energy stored level and pause until it enters the second time period, and then charge until the second energy stored level is reached. If the second energy stored level is reached before expiration of the second time period, the present system can maintain the second energy stored level. A user controllable interface is included in some examples and is connected to the charging cost circuit 2125 such that the user can input length of the second period during which charging takes place.

This section provides an overview of example hardware and the operating environments in conjunction with which embodiments of the inventive subject matter can be implemented.

A software program may be launched from a computer-readable medium in a computer-based system to execute functions defined in the software program. Various programming languages may be employed to create software programs designed to implement and perform the methods disclosed herein. The programs may be structured in an object-oriented format using an object-oriented language such as Java or C++. Alternatively, the programs may be structured in a procedure-oriented format using a procedural language, such as assembly or C. The software components may communicate using a number of mechanisms well known to those skilled in the art, such as application program interfaces or inter-process communication techniques, including remote procedure calls. The teachings of various embodiments are not limited to any particular programming language or environment. Thus, other embodiments may be realized, as discussed regarding FIG. 107 below.

FIG. 107 is a block diagram of an article 300S according to various embodiments of the present subject matter. Such embodiments may comprise a computer, a memory system, a magnetic or optical disk, certain other storage device, or any type of electronic device or system. The article 300S may include one or more processor(s) 306S coupled to a machine-accessible medium such as a memory 302S (e.g., a memory including electrical, optical, or electromagnetic elements). The medium may contain associated information 304S (e.g., computer program instructions, data, or both) which, when accessed, results in a machine (e.g., the processor(s) 306S) performing the activities described herein.

Various methods disclosed herein provide for battery charging based on cost and life. As mentioned above, certain examples charge batteries with electricity derived from a municipal power grid. In some instances, this electricity is less expensive during certain times of the day. In particular, many parts of the world offer less expensive energy during evening times. The present subject matter provides methods that can automatically charge a vehicle in consideration of such less expensive charging cost rates. The present subject matter, however, is also functional under a manual operation scheme, in which a person is able to select an amount of energy to receive during a first period of time (e.g., a period of time when electricity is less expensive), and during a first period of time (e.g., a period of time when electricity is more expensive).

FIG. 108 is a method of charging a battery, according to one embodiment of the present subject matter. At 402S, the method includes determining charging cost rate. At 404S, the method includes charging a battery of an electric vehicle to a first energy stored level while a first charging cost rate is determined. At 406S, a decision is made: should the system charge to a second energy stored level? If yes, at 408S, the system charges the battery to a second energy stored level while a second charging cost rate is determined that is higher than the first energy stored level. If no, the method ends. Various optional features are combinable with the present methods. For example, in certain optional methods, the first charging cost rate is lower than the second charging cost rate. But some methods are contemplated in which the first charging cost rate is higher than the second charging cost rate.

Various options are contemplated. As stated elsewhere, examples in which a system does not charge fully, but will charge more fully when instructed to, are contemplated. In certain embodiments, if a user plugs in their electric vehicle at night, it will charge to a first energy stored level and pause at that level. In some embodiments that level is 80% of capacity, but the present subject matter is not so limited. In certain examples, unless the user instructs the electric vehicle to charge even more, the vehicle will not charge more. In certain instances, a push button is provided in an electric vehicle charging system that enables a user to instruct the system to add more charge. Such a push button could be operated in the morning, in some instances, shortly before a user realizes they should use their car to drive longer distances before recharging than normal.

In some embodiments, a system is provided that is able to store a battery at a energy stored level that improves calendar life. In certain examples, this energy stored level is
50% of capacity. This energy stored level can be monitored over time and maintained. The stored energy level maintenance mode is entered into upon a user input, in some examples. In additional embodiments, a vehicle realizes that it has been dormant for a period of time that exceeds a threshold, and enters a storage mode. Various examples recognize dormancy in other ways, such as by monitoring the odometer or reading other instruments. Storage mode can be indicated by a horn sound or with another indicator, such as a flashing light.

[0589] FIG. 109 is a method of charging a battery to a first energy stored level during a first time period 5045S and charging the battery during a second time period 5065S, according to one embodiment of the present subject matter. Illustrated is an example in which a battery is charged until the first energy stored level 5025S is reached. In various embodiments, this charging is limited to a first time period 5045S. In various examples, the first time period is coincident with the time of day in that a first charging cost rate is within in a first cost range.

[0590] Additional embodiments charge the battery until the second energy stored level 5085S is reached. In various examples, this occurs during a second time period 5065S. In certain instances, the second time period 5065S is user selected. In some embodiments, the second time period 5065S is coincident with a period of time in which a charging cost rate fits into a second cost range that is different from a first cost range. In certain examples, the second energy stored level 5085S is less than a full energy stored level. The illustrated embodiment shows that the electric vehicle was unplugged shortly before it reached the second energy stored level 5085S. This may be exhibited in examples in which a user decides to leave before the second time period ends.

[0591] FIG. 110 is a method of charging a battery during a second time period, according to one embodiment of the present subject matter. Embodiments of the present subject matter include charging the battery to the second energy stored level only if so instructed by a stored indicator, as discussed above.

[0592] Some examples include predicting a daily charge stop time 6025S based on an energy usage pattern. Some instances prompt a user to select between improved calendar life and reduced cost. Embodiments that prompt a user for information include storing a user response as the stored indicator. In various examples, if the stored indicator indicates improved calendar life, the method charges to the second energy level by delaying charging to the second energy level until charging can occur constantly up to the predicted daily charge stop time such that the second energy stored level is reached. The present illustration shows that the battery of an electric vehicle was already charged near a regular stored charge, and elected to not charge the battery during the first time period. The electric vehicle charging system additionally recognized a charge stop time, and commenced charging such that it could reach the second energy stored level 6045S at the charge stop time 6025S. Such a system can improve calendar life of a battery. Various embodiments include electing to not charge to the second energy stored level.

[0593] FIG. 111 is a method of charging to a first energy stored 7105S level during a first time period, and to a second energy stored 7125S level during a second time period, according to one embodiment of the present subject matter. Various embodiments include charging the battery according to a charging schedule that includes a first time period 7025S and a second time period 7045S, the first energy stored level 7105S reached (during the e time period) within the first time period 7025S, the second energy stored level 7125S (during the q time period) reached during the second time period 7045S.

[0594] Some examples include predicting a daily cost based on an energy usage pattern. Some instances adjust the length of the first time period and length of the second time period such that a total cost of charging to the second energy stored level is less than the predicted daily cost.

[0595] Some examples include predicting a daily charge stop time 7065S based on an energy usage pattern. Some of these examples include delaying (during the μ time period) charging to the second energy level until charging can occur constantly up to the predicted daily charge stop time 7065S. In some instances, this occurs such that the second energy stored level 7125S is reached. Embodiments are included in which no charging occurs during at least a portion of the second time period 7045S.

[0596] FIG. 112 is a method of charging a battery in the context of a charging rate that varies up and down throughout the day, according to one embodiment of the present subject matter. A charge rate 8025S is determined and varies. A battery energy stored level 8045S is charted in the illustration. In various embodiments, if the charging rate is at a first charge cost rate 8065S, the battery charges on its way to a first energy stored level 8105S. If the system reaches this level, it stops charging if it is during the first time period. For example, a first time period, defined by the addition of time periods α, β, and γ is illustrated. During this time, the system charges only when the charging cost rate is within the first charging cost rate range 8065S. Starting after time period β, the illustration enters a second time period in which it is acceptable to charge as the second charging cost rate range 8085S. The illustration reaches a second stored energy level 8125S, and does not add more charge during the γ time period, during that the second charging cost rate is realized, nor after that time period, during which the first charging cost rate is realized.

[0597] Such a system could be helpful in areas in which municipal power grid pricing fluctuates frequently, such as in areas where wind turbines produce excess power at windy times, and a shortage of power during times in which it is not windy. Various examples include receiving a cost signal and charging at one of the first charging cost rates and the second charging cost rate in response to that cost signal.

[0598] FIG. 113 is a method according to one embodiment of the present subject matter. At 9025S, the method includes storing a user selected driving range for an electric vehicle. At 9045S, the method includes determining a potential driving range based on a pattern of driving ranges achieved by charging a battery of the electric vehicle to a first percentage of capacity. At 9065S, the method includes determining whether a first amount of energy stored when the battery is charged to the first percentage of capacity is sufficient to achieve the user selected driving range based on the pattern of driving ranges achieved. At 9085S, the method includes charging the battery to the first percentage of capacity if the first amount energy stored is sufficient to power the electric vehicle through the selected driving range. At 9105S, the method includes charging the battery to a second percentage of capacity, which is higher than the first percentage of capacity, if the first energy stored is not sufficient to power the electric vehicle through the user selected driving range. In certain examples, the second energy stored level is 100%.
FIG. 114 is a method of charging a battery to achieve a selected range, according to one embodiment of the present subject matter. A life cycle of a battery always charged to a regular capacity 1002S is illustrated, with a regular end of life 1010S. This is the energy stored when the battery is charged to a specific capacity, such as 80%, that is less than full capacity. Additionally illustrated is a life cycle of a battery always charged to a full capacity 1004S, with a full end of life 1006S. A hybrid curve 1012S is illustrated for a battery which is at first charged to a regular capacity, and then to a capacity that is more than the regular capacity, demonstrating a hybrid end of life 1008S. In the illustration, the hybrid begins to charge a battery at a capacity higher than a regular capacity starting at a certain time 1014S, although the present subject matter is not so limited. The time hybrid starts to charge to a capacity in excess of the regular capacity commences can coincide with the time that energy stored when charged to regular capacity starts to diminish. The penalty for charging the hybrid higher than the regular capacity is an earlier end of life 1008S than the end of life 1010S enjoyed by batteries always charged to regular capacity. Battery capacity has a linear relationship with voltage in some examples, and certain instances charge to respective voltages in certain examples.

The hybrid curve assists in a user to consistently maintain a usable driving range. For example, if energy stored for a certain capacity starts to diminish, as it does for the regular capacity curve 1002S after a certain time 1014S, driving range for that capacity also diminishes. But some users desire to avoid diminished range. As such, the present subject matter charges to a higher capacity, following the hybrid curve 1012S. This provides a compromise between ensuring some time during which a longer range is realized, and shortening the end of life of the battery.

Various examples of the present subject matter automatically track decreasing range based on an energy use pattern. Some of these embodiments switch to a hybrid curve automatically, so a user does not realize range is decreasing. In some embodiments, switching to the hybrid curve occurs only if the end of life is predicted to occur within the warranty period of an electric vehicle. Some embodiments provide an alert to the user when charging to a hybrid capacity has begun. In some instances the hybrid curve includes a series of incremental upward adjustments to capacity. In some embodiments, capacity is increased by 0.05% a day. Other increases are contemplated.

In some embodiments, a vehicle system drives a first range during some driving sessions and a second range during additional driving sessions, and a user selects which range to drive. In some of these embodiments, a vehicle charging system automatically selects which of the regular capacity and the hybrid capacity to use depending on the user selected range.

In the following description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present invention. The following description of example embodiments is, therefore, not to be taken in a limited sense, and the scope of the present invention is defined by the appended claims.

FIG. 115 is a high level diagram of an electric vehicle with a battery and a charging indicator, according to one embodiment of the present subject matter. An electric vehicle 102T is illustrated. Electric vehicles include, but are not limited to, ground based vehicles, aquatic vehicles, and aircraft. For the purposes of explanation, the present subject matter focuses on ground based vehicles. Plug-in hybrids and range extending vehicles are contemplated. Some embodiments of the present subject matter include a battery 104T mounted to the vehicle 102T. Various batteries are contemplated. The present subject matter includes embodiments in which the battery 104T is a secondary battery that is rechargeable using electricity rather than chemicals or other materials. Various secondary battery chemistries are contemplated, including lithium ion battery chemistries, but the present subject matter should not be construed to be limited to lithium ion or any other battery chemistry.

Various embodiments include a charge state circuit 106T located in the electric vehicle 102T and coupled to the battery 104T. In various embodiments, the charge state circuit 106T is configured to provide a charge state signal indicative of the charge state of the battery 104T. A charge state circuit 106T, in some embodiments, is a voltage meter. Other charge state circuits 106T are used in additional embodiments, including, but not limited to, current meters, coulomb counter, thermal meters, and other meters capable of monitoring how much energy is stored in a battery 104T.

Various embodiments include a charging coupler port 108T located proximate to a user accessible exterior of the electrical vehicle 102T and coupled to the battery 104T. In various embodiments, the charging coupler port 108T communicates charging energy to the battery 104T. In some examples, this includes hardware to at least partially form a conductive path from the battery 102T to a conductive terminal of the charging coupler port 108T. Some embodiments include one or more female terminals configured to receive a mating male terminal. Embodiments in which the charging coupler port 108T includes male terminals are contemplated. In some embodiments, the charging coupler port 108T is itself conductive and is in conductive communication with the battery 102T. Inductive embodiments are contemplated, in which a field is used to communicate energy.

In some embodiments, a male terminal is part of a charging coupler 110T. In various embodiments, a charging coupler 110T is a handheld connector mateable to the charging coupler port 108T. Some embodiments include a charging coupler 110T which is conductive and which mates to one or more terminals of the charging coupler port 108T. Various embodiments, however, include additional structure so that a user can handle the charging coupler 110T without being exposed to harmful shock.

In various embodiments, the charging coupler port 108T provides a charger connection signal indicative of a connection to an external power source 112T. The external power source is a charging station which is connected to a municipal power grid in some embodiments, but the present subject matter is not so limited. Batteries, generators, and other power sources comprise the external power source 112T in various embodiments.

Various embodiments, include a lighting circuit 114T coupled to the charging coupler port 108T and the charge state circuit 106T to control the brightness and color of an illuminated indicator 116T responsive to the charge state signal and the charger connection signal. The illuminated
indicator 116T is a computer monitor in some embodiments. In additional embodiments, the illuminated indicator 116T includes at least one multi-color lamp. In some embodiments, the illuminated indicator includes at least one multi-color LED. Various embodiments include a plurality of lamps. Some embodiments include a plurality of single color LEDs. Some embodiments include a mixture of multi-color LEDs and single-color LEDs. In various embodiments, the illuminated indicator 116T includes a white LED and the at least one lighting circuit is configured to illuminate the illuminated indicator to a white color by illuminating the white LED.

**[0610]** FIG. 116 shows a vehicle system 200T, according to one embodiment of the present subject matter. In various embodiments, the vehicle 202T is an electric vehicle and includes a vehicle propulsion battery 204T and at least one propulsion motor 206T for converting battery energy into mechanical motion, such as rotary motion. The present subject matter includes examples in which the vehicle propulsion battery 204T is a subcomponent of an energy storage system (“ESS”). An ESS includes various components associated with transmitting energy to and from the vehicle propulsion battery 204T in various examples, including safety components, cooling components, heating components, rectifiers, etc. The inventors have contemplated several examples of ESSs and the present subject matter should not be construed to be limited to the configurations disclosed herein, as other configurations of a vehicle propulsion battery 204T and ancillary components are possible.

**[0611]** The battery includes one or more lithium ion cells in various examples. In some examples, the battery 204T includes a plurality of lithium ion cells coupled in parallel and/or series. Some examples include cylindrical lithium ion cells. In some examples, the battery 204T includes one or more cells compatible with the 18650 battery standard, but the present subject matter is not so limited. Some examples include a first plurality of cells connected in parallel to define a first brick of cells, with a second plurality of cells connected in parallel to define a second brick of cells, with the first brick and the second brick connected in series. Some embodiment connect 69 cells in parallel to define a brick. Battery voltage, and as such, brick voltage, often ranges from around 3.6 volts to about 4.2 volts in use. In part because the voltage of batteries ranges from cell to cell, some embodiments include voltage management systems to maintain a steady voltage. Some embodiments connect 9 bricks in series to define a sheet. Such a sheet has around 35 volts. Some embodiment connect 11 sheets in series to define the battery of the ESS. The ESS will demonstrate around 385 volts in various embodiments. As such, some examples include approximately 6,831 cells which are interconnected.

**[0612]** Additionally illustrated is a energy converter 208T. The energy converter 208T is part of a system which converts energy from the vehicle propulsion battery 204T into energy useable by the at least one propulsion motor 206T. In some instances, the energy flow is from the at least one propulsion motor 206T to the vehicle propulsion battery 204T. As such, in some examples, the vehicle propulsion battery 204T transmits energy to the energy converter 208T, which converts the energy into energy useable by the at least one propulsion motor 206T to propel the electric vehicle. In additional examples, the at least one propulsion motor 206T generates energy that is transmitted to the energy converter 208T. In these examples, the energy converter 208T converts the energy into energy which can be stored in the vehicle propulsion battery 204T. In some examples, the energy converter 208T includes transistors. Some examples include one or more field effect transistors. Some examples include metal oxide semiconductor field effect transistors. Some examples include one more insulated gate bipolar transistors. As such, in various examples, the energy converter 208T includes a switch bank which is configured to receive a direct current (“DC”) power signal from the vehicle propulsion battery 204T and to output a three-phase alternating current (“AC”) signal to power the vehicle propulsion motor 206T. In some examples, the energy converter 208T is configured to convert a three-phase signal from the vehicle propulsion motor 206T to DC power to be stored in the vehicle propulsion battery 204T. Some examples of the energy converter 208T convert energy from the vehicle propulsion battery 204T into energy usable by electrical loads other than the vehicle propulsion motor 206T. Some of these examples switch energy from approximately 390 Volts to 14 Volts.

**[0613]** The propulsion motor 206T is a three phase alternating current (“AC”) propulsion motor, in various examples. Some examples include a plurality of such motors. The present subject matter can optionally include a transmission or gearbox 210T in some examples. While some examples include a 2-speed transmission, other examples are contemplated. Manually clutched transmissions are contemplated, as are those with hydraulic, electric, or electrohydraulic clutch actuation. Some examples employ a dual-clutch system that, during shifting, phases from one clutch coupled to a first gear to another coupled to a second gear. Rotary motion is transmitted from the transmission 210T to wheels 212T via one or more axles 214T, in various examples.

**[0614]** A vehicle management system 216T is optionally provided which provides control for one or more of the vehicle propulsion battery 204T and the energy converter 208T. In some examples, the vehicle management system 216T is coupled to vehicle system which monitors a safety system (such as a crash sensor). In some examples the vehicle management system 216T is coupled to one or more driver inputs (e.g., an accelerator). The vehicle management system 216T is configured to control power to one or more of the vehicle propulsion battery 204T and the energy converter 208T, in various embodiments.

**[0615]** External power 218T is provided to communicate energy with the vehicle propulsion battery 204T, in various examples. In various embodiments, external power 218T includes a charging station that is coupled to a municipal power grid. In some examples, the charging station converts power from a 110V AC power source into power storabe by the vehicle propulsion battery 204T. In additional examples, the charging station converts power from a 220V AC power source into power storabe by the vehicle propulsion battery 204T. Voltages in the range of from about 208 volts to about 240 volts are contemplated. Some embodiments include converting energy from the battery 204T into power usable by a municipal grid. The present subject matter is not limited to examples in which a converter for converting energy from an external source to energy usable by the vehicle 200T is located outside the vehicle 200T, and other examples are contemplated.

**[0616]** In various embodiments, the external power 218T is coupled to a charging coupler 220T. This charging coupler 220T is matable to a charging coupler 222T, in various embodiments. In various embodiments, the charging coupler port 222T includes an illuminated indicator 224T. The illu-
minated indicator includes a lamp disposed proximate to a body panel of the electrical vehicle 202T in some embodiments. The lamp includes an LED in some embodiment. In additional embodiments, other lamps are used. In some embodiments, the illuminated indicator lights the exterior of the vehicle 202T and the charging coupler port 222T. In some embodiments, the illuminated indicator lights only the charging coupler port 222T.

[0617] Some examples include a vehicle display system 226T. The vehicle display system 226T include a visual indicator of system 200T information in some embodiments. The vehicle display system 226T includes the illuminated indicator in some embodiments. In some embodiments, the vehicle display system 226T includes a monitor that includes information related to system 200T. Some embodiments include one or more lights. Some embodiments include one or more lights, and the vehicle display system 226T in these embodiments includes the illumination and brightness of these lights. The vehicle management system, in some embodiments, coordinates the function of a charge state circuit 106T, and the charging coupler port 108T, as pictured in FIG. 115. In certain instances, the charge state circuit 106T, and the charging coupler port 108T are part of the vehicle management system 216T. In some instances, the lighting circuit 116T is part of the vehicle display system 226T. In some embodiments, the illuminated indicator 116T of FIG. 115 is part of the vehicle display system 226T.

[0618] FIG. 117 illustrates a partial perspective view of a system including an electric vehicle, a charger, a charging coupler port, and other components, according to one embodiment. FIG. 118 illustrates a cross section along line 4-4 in FIG. 117. An electric vehicle 302T is pictured. The electric vehicle 302T includes a charging coupler port recess 304T. The charging coupler port recess 304T includes a charging coupler port 306T which is in electrical communication with a battery of the electrical vehicle 302T. A charging station 308T includes a charging coupler 310T which includes a charging coupler terminal 312T. Although blade terminals are shown for the charging coupler port 304T and the charging coupler 310T, other terminals are contemplated, such as rod type, pin and socket type, pads, and other types. In some embodiments, the charging station 308T is coupled to a municipal power grid 314T.

[0619] In various embodiments, a lens 318T is disposed between the body panel 320T and the charging coupler port 306T. In various embodiments, the lens 318T and the charging coupler port 306T at least partially define the recess 304T in the electric vehicle 302T. In various embodiments, an illuminated indicator is shielded from the recess 304T by the lens 318T. FIG. 118 illustrates an embodiment in which a lens 318T shields a first illuminated indicator 402T and a second illuminated indicator 404T from the recess 304T. The illuminated indicators in FIG. 118 can be mounted on printed circuit boards, or can couple to the electric vehicle 302T in other ways. Although two illuminated indicators are shown, embodiments in which a single illuminated indicator is used are possible, as are ones with more than two illuminated indicators. The lens 318T is shown tapering down from the body panel 320T to the charging coupler port 306T, but the present subject matter is not so limited.

[0620] In some embodiments, the lens 318T is a diffuser. In some embodiments, the lens 318T is part of a lamp. The lens 318T can comprise a neon lamp, an LED lamp, an incandescent, or any other arc or non-arc light emitter, according to various embodiments. In some embodiments, the lens 318T includes an illuminated indicator light pipe. In some embodiments, the lens 318T casts light on the charging coupler port 306T. In additional embodiments, the lens 318T casts light on the exterior body panel 320T. Some embodiments include a lens 318T that casts light on both the charging coupler port 306T and the exterior body panel 320T.

[0621] In an alternative embodiment, lamps that are used primarily for other purposes on the vehicle are used in place of, or in addition to, lens 318T. In various embodiments, this includes, but is not limited to, directional lamps, headlamps, stop lamps, running lamps, interior lamps, and other lamps.

[0622] Embodiments are included in which the lens 318T is at least partially arcuate and encircles the charging coupler port along the exterior of the vehicle, as pictured in FIGS. 117-118. Additional configurations are contemplated, includes those in that the lens 318T is substantially rectangular and borders the charging coupler port. Other shapes are possible, and it is not necessary that the lens 318T encircle or otherwise circumscribe the charging coupler port 306T. In some embodiments, a charging coupler port door 316T at least partially covers a charging coupler recess 304T which contains the charging coupler port 306T. In some embodiments, the charging coupler port door 316T is coupled to the vehicle using a hinge 324T. In some embodiments, a lighting circuit (e.g., the lighting circuit 116T illustrated in FIG. 115) is configured to operate the illuminated indicator and to deliver a white color if a charging coupler is not coupled to the charging coupler port 306T and the charging coupler port door is in an open state, as illustrated. In some instances, a switch is coupled to the charging coupler port door 316T and the lighting circuit to define a conductive path to the lighting circuit when the charging coupler port door 316T is open. In some instances, this lighting circuit monitors the conductive path and operates an illuminated indicator when the charging coupler port door 316T is in an open state. In various embodiments, this illuminates lens 318T so it casts visible light on at least the charge port coupler 306T.

[0623] FIG. 119 illustrates a perspective view of a charging coupler port, according to one embodiment. The illustration is highly detailed, and other configurations that differ from that shown are possible depending on which embodiment is studied. The illustration shows a conductive path. The conductive path at least partially includes the wiring bundle (also known as a harness or loom) 502T. The wiring bundle is part of the charging coupler port 504T. A lens assembly 506T is illustrated that includes a light pipe 508T including a diffusive surface 509T and a plurality of LEDs disposed between a printed circuit board and the light pipe 508T. A hinge 510T is shown.

[0624] A charging coupler port door 512T is shown. This is coupled to the hinge 510T. This door is to cover a recess in that the charging coupler port 504T is disposed. A fixture 514T is shown that is used to assist in coupling the charging coupler port 502T, the lens assembly 506T, and the hinge 510T to an electric vehicle. A lock 516T is shown that is used to lock a first lock portion 518T to a mating lock portion 520T such that the hinge 510T is restricted from motion. A spring 521T is shown that allows the first lock portion 518T to snap into a mating relationship with mating lock portion 520T. The power of the spring can be overcome to open the charging coupler port door 512T, in various embodiments. This can be useful for safety and security, as it is desirable to prevent others from tampering with the charging coupler port.
A plurality of fasteners are collectively labeled 522T and are included for clarity, but can be reconfigured as needed in different embodiments. 

[0625] FIG. 120 illustrates a method 600T for indicating charge, according to one embodiment. At 602T, the method includes connecting a charging coupler to a charging coupler port of an electric vehicle. Various embodiments include opening a charging coupler port door which is hinged to the electric vehicle and which at least partially covers the charging coupler port prior to connecting the charging coupler to the charging coupler port of the electric vehicle. At 604T, the method includes communicating a charger connection signal indicative of the state of connection of the charging coupler and the charging coupler port to a lighting controller. At 606T, the method includes determining a charge state signal indicative of the charge state of a battery coupled to the electric vehicle. At 608T, the method includes communicating the charge state signal to the illuminated indicator controller.

[0626] At 610T, the method includes providing an external indication of the charger connection signal and the charge state signal by controlling the brightness and the color of illuminated indicator coupled to the charging coupler port. In optional embodiments, the method includes illuminating the charging coupler port with the at least one illuminated indicator while a charging coupler port door coupled to the vehicle and covering a recess in which the charging coupler port is located is open. In some embodiments, the method includes controlling the illuminated indicator to a blue color if the charging coupler is coupled to the charging coupler port and the charging coupler port is not transmitting charging energy. Some example embodiments include a method that includes determining a target charge state, comparing the charge state to the target charge state and controlling the illuminated indicator to a green color if the charge state exceeds the target charge state.

[0627] Certain embodiments include detecting a first electrical vehicle fault with a fault detection circuit and controlling the illuminated indicator to a red color if the first electrical vehicle fault is detected. Certain additional embodiments include flashing the illuminated indicator to a red color if the first electrical vehicle fault is detected. In some embodiments, a method includes detecting a second electrical vehicle fault with the fault detection circuit. Some of these embodiments include varying the illumination of the illuminated indicator over time responsive to the second fault signal. Various faults are contemplated. For example, if one of a plurality of batteries malfunctions, a fault can be indicated. In one embodiment, a vehicle performs a system check and if a fault is detected, and the illuminated indicator lights red when the charging coupler port door is opened. In some of these embodiments, the light is solid.

[0628] Various embodiments include a method that includes controlling the illuminated indicator to a yellow color if the charging coupler is coupled to the charging coupler port and the charging coupler port is transmitting charging energy. In some of these embodiments, the method includes pulsing the illuminated indicator when the charging coupler port is transmitting charging energy. In some of these embodiments, the method includes pulsing illuminated indicator at a first frequency when the charge state of the battery is at a first charge, and at a second frequency, which is less than the first frequency, when the charge state of the battery is at a second charge which is higher than the first charge. Optional embodiments include pulsing the illuminated indicator at a first frequency when the charge state of the vehicle propulsion battery is at a first charge, and at a second frequency, which is less than the first frequency, when the charge state of the vehicle propulsion battery is at a second charge which is higher than the first charge.

[0629] In the following description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present invention. The following description of example embodiments is, therefore, not to be taken in a limited sense, and the scope of the present invention is defined by the appended claims.

[0630] FIG. 121 shows an electric vehicle system 100U according to one embodiment of the present subject matter. In various embodiments, the vehicle 102U is an electric vehicle and includes a vehicle propulsion battery 104U and at least one propulsion motor 106U for converting battery energy into mechanical motion, such as rotary motion. The present subject matter includes examples in which the vehicle propulsion battery 104U is a subcomponent of an energy storage system ("ESS"). An ESS includes various components associated with transmitting energy to and from the vehicle propulsion battery in various examples, including safety components, cooling components, heating components, rectifiers, etc. The inventors have contemplated several examples of ESS, and the present subject matter should not be construed to be limited to the configurations disclosed herein, as other configurations of a vehicle propulsion battery and ancillary components are possible.

[0631] The vehicle propulsion battery 104U includes a lithium ion battery in various examples. In some examples, the vehicle propulsion battery 104U includes a plurality of lithium ion batteries coupled in parallel and/or series. Some examples include cylindrical lithium ion batteries. In some examples, the ESS includes one or more batteries compatible with the 18650 battery standard, but the present subject matter is not so limited. Some examples include approximately 2981 batteries which are interconnected. The vehicle propulsion battery 104U, in some examples, provides approximately 390 volts.

[0632] Additionally illustrated is an energy converter 108U. The energy converter 108U is a part of a system which converts energy from the vehicle propulsion battery 104U into energy useable by the at least one propulsion motor 106U. In some instances, the energy flow is from at least one propulsion motor 106U to the vehicle propulsion battery 104U. As such, in some examples, the vehicle propulsion battery 104U transmits energy to the energy converter 108U, which converts the energy into energy useable by the at least one propulsion motor 106U to propel the electric vehicle. In additional examples, at least one propulsion motor 106U generates energy that is transmitted to the energy converter 108U. In these examples, the energy converter 108U converts the energy into energy which can be stored in the vehicle propulsion battery 104U. In some examples, the energy converter 108U includes transistors. Some examples include one or more field effect transistors. Some examples include metal oxide semiconductor field effect transistors. Some examples include one or more insulated gate bipolar transistors. As
such, in various examples, the energy converter 108U includes a switch bank which is configured to receive a direct current ("DC") power signal from the vehicle propulsion battery 104U and to output a three-phase alternating current ("AC") signal to power the vehicle propulsion motor 106U. In some examples, the energy converter 108U is configured to convert a three-phase signal from the vehicle propulsion motor 106U to DC power to be stored in the vehicle propulsion battery 104U. Some examples of the energy converter 108U convert energy from the vehicle propulsion battery 104U into energy usable by electrical loads other than the vehicle propulsion motor 106U. Some of these examples switch energy from approximately 390 Volts to approximately 14 Volts.

10633] The propulsion motor 106U is a three phase AC propulsion motor, in various examples. Some examples include a plurality of such motors. The present subject matter can optionally include a transmission 110U in some examples. While some examples include a 2-speed transmission, other examples are contemplated. Manually clutched transmissions are contemplated, as are those with hydraulic, electric, or electrohydraulic clutch actuation. Some examples employ a dual-clutch system that, during shifting, phases from one clutch coupled to a first gear to another clutch coupled to a second gear. Rotary motion is transmitted from the transmission 110U to wheels 112U via one or more axles 114U, in various examples.

10634] A vehicle management system 116U is optionally provided which provides control for one or more of the vehicle propulsion battery 104U and the energy converter 108U. In some examples, the vehicle management system 116U may be coupled to vehicle systems which monitors safety (such as a crash sensor). In some examples the vehicle management system 116U may be coupled to one or more driver inputs (such as a speed adjuster or accelerator, colloquially termed a throttle, although the present subject matter is not limited to examples having an actual throttle). The vehicle management system 116U may be configured to control power to one or more of the vehicle propulsion battery 104U and the energy converter 108U, in various embodiments. According to other embodiments, the VMS may serve as a liaison between the ESS and the cooling system but may not interact with the throttle pedal, gear selector, or other functions.

10635] A charging station 118U may be provided to transmit energy with the vehicle propulsion battery 104U, in various examples. In some examples, the charging station converts power from a 110V AC power source into power storable by the vehicle propulsion battery 104U. In additional examples, the charging station converts power from a 220V AC power source into power storable by the vehicle propulsion battery 104U. The present subject matter is not limited to examples in which a converter for converting energy from an external source to energy usable by the vehicle 102U is located outside the vehicle 102U, and other examples are contemplated.

10636] A heating, ventilation and air conditioning ("HVAC") system 120U may be provided to perform various heating and cooling functions within the electric vehicle 102U. The HVAC system 120U may provide cooled or heated air to the cabin environment for the comfort of the passengers in some embodiments. Additionally, the HVAC system may provide heating and cooling for various mechanical and electrical components of the vehicle 102U. The HVAC system 120U need not have both heating and cooling capabilities. Heating and cooling may optionally be produced separately, using one or more additional components. According to some embodiments, the HVAC system 120U may provide cooling to the battery 104U. In some examples, the life and operational efficiency of the battery 104U may be affected by temperature. In order to maintain the battery in a good operating condition, cooling from the HVAC system 120U may be provided to the battery 104U in calculated amounts. The HVAC 120U may itself be powered off of voltage from the battery 104U. This voltage may be converted to a suitable voltage by the energy converter 108U before it is used by the HVAC system 120U in accordance with some embodiments. Further operations of the HVAC system, 120U, specifically with regard to battery cooling may be described below.

10637] FIG. 122 is a block diagram of a system 200U for cooling a battery and cabin according to various embodiments. The system 200U includes a cooling subsystem 202U, a battery circulation subsystem 204U, a cabin circulation subsystem 206U, and a control 208U.

10638] The cooling subsystem 202U may include one or more components which are operable to create a reduction in temperature. The reduction in temperature may be brought on in a number of ways, including compressing a refrigerant according to one embodiment. The refrigerant may be tetrafluoroethane or R134a, as commonly used in vehicles, or another refrigerant. Additionally, the cooling subsystem 202U may operate using a thermal electric technique that may use a solid state "Peltier" device such that the cooling subsystem 202U would not necessitate the use of a refrigerant. These and other cooling methods may be used by the cooling subsystem 202U, although the inventive subject matter is not limited to any particular method of cooling within the cooling subsystem 202U.

10639] The battery circulation subsystem 204U may include one or more components which are operable to transfer cooling and reduce the heat in a battery. Fluid from the cooling subsystem 202U may be routed to the battery circulation subsystem 204U to reduce the heat in the battery. If the fluid is a refrigerant, an expansion valve, evaporator and/or a heat exchanger may be used as part of the battery circulation subsystem 204U. According to various embodiments, the heat exchanger may cool a coolant which may be routed in thermal contact with the battery. Additionally, according to other embodiments, a fan may blow air over the evaporator and route the cooled air across the battery. Other methods for removing heat from the battery may be used as well.

10640] The cabin circulation subsystem 206U may be used to provide cooling to the cabin of a vehicle according to various embodiments. In some embodiments, the cabin circulation subsystem may include fans, ducting, and venting as traditionally found in automobiles, although the inventive subject matter is not limited in this respect. If the cooling subsystem 202U provides a compressed refrigerant, the cabin circulation subsystem 206U may include an expansion valve and evaporator for the refrigerant. Fans may blow air over the evaporator to provide cooled air to the cabin. Other methods for cooling the cabin using the cabin circulation subsystem may be used according to other embodiments.

10641] A control 208U may be present to regulate the movement of fluid or other cooling medium between the cooling subsystem 204U and at least one of the battery circulation subsystem and the cabin circulation subsystem 206U. The control 208U may operate automatically based on
programming implemented by a processor, it may be manually controlled, or may be a combination thereof.

[0042] FIG. 123 is a block diagram of a system 300U for cooling multiple zones according to various embodiments. The system 300U includes a cooling subsystem 302U, a first zone 304U, a battery zone 306U, a valve 308U, and a processor 310U.

[0043] The cooling subsystem 302U may be similar to the cooling subsystem 202U described above with reference to FIG. 122. The cooling subsystem 302U may utilize one or more cooling techniques using various technologies to provide cooling to the first zone 304U and/or to the battery zone through the valve 308U. Other zones may additionally be in communication with, or coupled to, the cooling subsystem through the valve 308U or other additional valves.

[0044] The first zone 304U, or any additional zones may include the cabin of a vehicle, a motor, an engine, an additional battery, or other component or space which may use cooling. The battery zone 306U includes a battery which may provide increased efficiency when cooled effectively. The first zone 304U and the battery zone 306U may be in communication with the cooling subsystem through the valve 308U. According to various embodiments, the valve 308U may regulate the fluid communication between the cooling subsystem and the first zone 304U and the battery zone 306U. Additionally, according to some embodiments, the valve 308U may consist of multiple valves individually regulating cooling to one or more zones.

[0045] The processor 310U may monitor the temperature of the battery zone 306U in order to determine whether or not the battery is above certain thresholds. Temperature thresholds may be defined to trigger when the battery needs cooling, when the battery is heated above a safe operational temperature and other thresholds. When the processor determines that the battery zone 306U is to be cooled, it signals the valve 308U to allow communication between the cooling subsystem 302U and the battery zone 306U, thus reducing heat rise in the battery zone 306U. The processor may act in accordance with one or more algorithms to attempt to maintain the battery within ideal operational temperatures, while also taking into consideration prioritization of cooling between zones and energy efficient operation of the cooling subsystem 302U. Examples of these algorithms are described with reference to FIG. 124 and FIG. 125 below.

[0046] FIG. 124 is a flow diagram illustrating a method 400U for cooling a battery according to various embodiments. The method 400U begins by estimating the remaining operational time that the battery may run before it is effectively depleted (block 402U). The battery is effectively depleted, or has reached depletion when it can no longer supply the power necessary to perform a minimum amount of functionality. Depletion does not necessarily that the battery have no charge remaining, or that it registers zero (0) voltage between its terminals. According to an example embodiment, a battery may be considered depleted if the voltage between its terminals is measured at below 350 volts resting, when its nominal operating voltage is around 390 volts. Under load, however, the voltage may be allowed to drop below 350 volts without being considered depleted. In some embodiments, the voltage may drop below 250 volts under load before being considered depleted. Estimating the remaining operational time of the battery before depletion may entail measuring and calculating the average draw of power on the battery. In an electric vehicle, the power train provides one of the biggest draws on the battery, thus the activity of the power train may largely affect the estimate. Other factors such as operation of the cooling system and other electrical components may play into the estimate as well. Sporadic driving or use of electrical systems may influence the accuracy of the estimate.

[0047] During operation the temperature of the battery may be monitored, and if it is below a threshold, it may be allowed to rise without any application of cooling (block 404U). Temperature monitoring may be continuous or periodic, and the data measured may be used to determine the current temperature of the battery as well as the rate of change in its temperature.

[0048] Cooling may be strategically requested to be applied to the battery in order to increase efficiency as well as maintain the battery in a safe operating temperature range. Generally in an electric vehicle, the components used for providing cooling are electrically powered. In an example embodiment, an electrically driven compressor may be used to pressurize a refrigerant. In other embodiments, thermal electric components using solid state "Peltier" device may be employed to reduce heat. In any case, the system used to reduce the heat in the battery may require power from the battery. An algorithm may be used to efficiently cool the battery. Using the estimate of operational time remaining on the battery before it is depleted, cooling may be requested in an amount which is enough to assure that the battery stays below a peak threshold until it is depleted (block 406U). The peak threshold may represent the upper temperature limit that is within the safe operating range for the battery. This may represent a limit at which the lifetime of the battery is negatively affected with higher temperatures.

[0049] The method 400U allows the battery to only be cooled as much as is needed given the estimated time remaining that it will be used. Additionally, just as the temperature of the battery is being monitored continuously or periodically, the voltage level and power draw on the battery may also be monitored. With changing characteristics (including battery voltage, power draw, temperature, driving conditions and more...), the estimate of operational time before the battery is depleted (block 402U) may change, according to some embodiments. This changing estimate may affect the timing of any requests for cooling of the battery (block 406U). The amount of cooling to the battery may be variable based on the current battery temperature. The device providing the cooling may have variable levels of operation, and lower levels (drawing less power) may be used when less cooling is needed. In one example, if another zone such as the cabin is being cooled, varying levels of cooling may be routed to the battery at the expense of the cooling of the other zone. In some cases, according to various embodiments, cooling in the cabin may be sacrificed in order to cool the battery. The remaining time before depletion may also affect the amount of cooling to be delivered to the battery. In some cases, cooling of the battery may be avoided if the circumstances permit.

[0050] FIG. 125 is a flow diagram illustrating another method for cooling a battery according to various embodiments. The method 500U begins in a similar fashion as the method described with reference to FIG. 124. In addition to estimating the remaining operational time that the battery may run before it is effectively depleted (block 402U) and monitoring the battery temperature (block 404U), an additional estimation may be made. Based on the rate of rise of the battery temperature the time before the battery reaches a
temperature threshold may be estimated (block 50U). This temperature threshold may be the peak temperature threshold described above.

[0651] The estimated time before the battery reaches the threshold may be compared with the estimated operational time remaining before the battery is depleted. Cooling may be requested for the battery if the time before the battery temperature reaches the threshold is less than the remaining operational time before depletion of the battery (block 50U). If the time before the battery reaches the threshold is longer than the remaining operational time before the battery reaches depletion, cooling may not be requested, and battery power may be conserved.

[0652] FIG. 126 is a block diagram of an example system 600U according to some embodiments. The system 600U includes a compressor 602U, a valve 604U, an evaporator 606U, an evaporator fan 608U, a condenser 610U, a condenser fan 612U, a heat exchanger 614U, a coolant pump 616U, a battery 618U, a processor 620U and a temperature sensor 622U.

[0653] In the example embodiment illustrated by FIG. 126, the compressor 602U may compress a refrigerant. The refrigerant may be selected out of a number of potential compressible fluids, and may be, for example, R134a as mentioned earlier, although the inventive subject matter is not limited in this respect. The use of a particular refrigerant or any refrigerant at all is not a limiting factor. The compressed refrigerant may be directed through the valve 604U. The valve 604U may direct the refrigerant to an expansion valve and evaporator 606U assembly. Upon decompression in the evaporator 606U, refrigerant pulls heat from the evaporator 606U, cooling the evaporator 606U. The evaporator fan 608U may blow air over the evaporator 606U to cool the cabin of a vehicle. The refrigerant may then be routed through the condenser 610U where it may be cooled with the help from the condenser fan 612U. The refrigerant may then make its way back to the compressor 602U to begin the cycle again.

[0654] As the compressed refrigerant reaches the valve 604U, it may be directed to the heat exchanger 614U. The heat exchanger 614U may include an expansion valve allowing the refrigerant to expand. Since the expansion of the refrigerant is endothermic, it will pull heat from its surroundings. Also routed through the heat exchanger 614U is a coolant fluid. The coolant fluid may be cooled by the expanding refrigerant in the heat exchanger 614U. The refrigerant may again return through the condenser 610U. The cooled coolant fluid may be moved through the pump 616U into thermal contact with the battery 618U. The battery 618U may include a number of cells, and the coolant may be routed through the inside of the battery casing to provide more direct thermal contact with individual battery cells. The pump 616U may circulate the coolant fluid through the battery 618U and the heat exchanger 614U to maintain cooling of the battery 618U.

[0655] The processor 620U may regulate the operation of the compressor 602U, the valve 604U and optionally the pump 616U. The processor 620U may utilize algorithms, examples of which are discussed above with reference to FIG. 124 and FIG. 125. Data needed to execute the algorithms may be obtained by gathering temperature measurements from the battery 618U. A temperature sensor 622U may provide the temperature measurements to the processor 620U. The temperature sensor 622U may include one or more thermistors, thermocouples, or any other temperature measuring device. The temperature may be determined on a cell-by-cell basis or for the battery as a whole. The processor 620U may also measure the voltage across the battery 618U and/or the current. Multiple, continuous, or periodic measurements may be used to help estimate averages or trends in the power draw and battery temperature.

[0656] With collected data, the processor 620U may estimate the remaining operational time that the battery may run before it is effectively depleted, and the time before the battery reaches a temperature threshold. The collected data may include vehicle speed, transmission gearing, DC current or AC phase current, or other data used to assess power consumption and estimate heat generation based on assumptions about the driver and the drive. With these estimates, the processor 620U may regulate the compressor 602U and the valve 604U in order to provide necessary cooling for the battery while maintaining efficient use of power.

[0657] Embodiments include a vehicle including a battery to supply a flow of electrical energy, an electric motor arranged to propel the vehicle, and a first control circuit coupled between the battery and the motor to control the flow of electrical energy to the motor. Various embodiments of the vehicle include a first heat exchange loop thermally coupled with a heat exchanger and a heating element, the first heat exchange loop to circulate a first fluid to heat or cool a passenger cabin, and a second heat exchange loop thermally coupled with the heat exchanger, the second heat exchange loop to circulate a second fluid to heat or cool the battery and a second control circuit to couple a charger to the battery and to perform charging operations on the battery using a voltage source powered from a line source. In various embodiments, the control circuit includes a comparator circuit to register a difference between a battery voltage of the battery to a voltage of the line source. In various embodiments, the second control circuit is to couple the heating element between the voltage source and the battery when the difference exceeds a predetermined voltage value, and to bypass the heating element when the difference is less than the predetermined voltage value.

[0658] Various embodiments of the vehicle further include a third control circuit constructed and arranged to control circulation of the first and second fluids, responsive to at least one parameter relating to the performance of the battery. Various embodiments include a battery monitoring device to measure a first temperature of at least one of a plurality of rechargeable cells within the battery, wherein the at least one parameter relating to the performance of the battery includes the first temperature. In various embodiments, the second heat exchange loop includes a cooling tube to be in thermal communication with at least one of the plurality of rechargeable cells, and the second fluid includes a coolant. In various embodiments, the third control circuit is to control a coolant temperature using a circulation of the coolant, and the heat exchanger. Various embodiments of the vehicle further include a third heat exchange loop to be in thermal communication with the first control circuit, wherein the first control circuit includes electronic circuitry to conduct the flow of electrical energy. In various embodiments, the third heat exchange loop is to further be in thermal communication with the motor and in thermal communication with a radiator.

[0659] Embodiments include a vehicle including an electric motor to propel the vehicle, a battery including a first plurality of rechargeable cells coupled in parallel in a plurality of bricks to supply a flow of electrical energy to the motor,
and a first control circuit coupled between the battery and the motor to control the flow of electrical energy to the motor.

Various embodiments of the vehicle include a processor coupled to the plurality of bricks to identify at least one cell of the plurality of rechargeable cells that contains a weak short circuit and to deactivate such cells. Various embodiments of the vehicle include a further processor to be communicatively coupled to the plurality of bricks, the further processor to detect a reference voltage for each brick and to sample at least one of the plurality of bricks for a first voltage and compare the first voltage with the reference voltage, the further processor to replace the reference voltage with the first voltage if the first voltage is lower than the reference voltage, and to cause the first voltage to be lowered if the first voltage is higher than the reference voltage.

In various embodiments, the processor is to temporarily switch off cells of the plurality of rechargeable cells while monitoring the cells to detect a short circuit, and to determine that the at least one cell contains a short circuit when the at least one cell is switched off and a short circuit is not detected. Various embodiments of the vehicle further include a cooling tube including a first channel, the cooling tube to be thermally coupled with the battery, and to circulate a flow of coolant via the first channel, to heat or cool the battery.

In various embodiments, the cooling tube is to circulate a second flow of coolant, via a second channel to heat or cool the battery, the first flow of coolant and the second flow of coolant to provide a flow of heat from one or more of the first plurality of cells, in opposite directions.

In various embodiments, a first brick of the plurality of bricks includes a first conductor plate to be conductively coupled to at least one of the first plurality of rechargeable cells, and further including at least one fusible link to conductively couple the at least one of the first plurality of rechargeable cells with a first collector plate, the at least one fusible link to conductively decouple from the first collector plate based on a detection of threshold current flow between the at least one of the first plurality of rechargeable cells and the first collector plate.

Various embodiments of the vehicle further include a second brick of the plurality of bricks and a second collector plate to be conductively coupled to at least one of the plurality of rechargeable cells. In various embodiments, the first collector plate and the second collector plate are to be conductively coupled together in series via a fuse, the fuse to conductively decouple the first collector plate and the second collector plate based on a detection of a threshold current flow between the first collector plate and the second collector plate. In various embodiments, the first collector plate and the second collector plate are to be conductively coupled together via a flexible conductor. In various embodiments, at least one of the first plurality of rechargeable cells is coupled to a first conductor plate via a frangible conductor constructed and arranged to conductively decouple from the first conductor plate based on an exposure of the battery to at least one of a specified force, a specified vibration level or a specified thermal level. In various embodiments, the frangible conductor includes a wire made of an aluminum alloy. In various embodiments, the frangible wire has at least one of a specified thickness, a specified diameter or a specified length associated with at least one of a specific melting behavior or specific fusing behavior.

Various embodiments of the vehicle further include a material to thermally couple with a case of each of the first plurality of rechargeable cells, the material having a higher thermal conductivity than air, wherein the material is to transfer heat released from a first of the first plurality of rechargeable cells to at least a second of the first plurality of rechargeable cells.

Embodiments include a vehicle including a battery including a first plurality of rechargeable cells to supply a flow of electrical energy, a control circuit coupled to the battery, the control circuit to control the flow of energy, and an electric motor coupled to the control circuit to receive the flow of energy and to propel the vehicle. In various embodiments, the electric motor includes a rotor assembly having a plurality of copper bar conductors embedded into a rotor surface, the plurality of copper bar conductors being conductively coupled with one another, via a plurality of copper plugs.

In various embodiments, the electric motor includes a rotor shaft having a hollow portion and a coolant feed tube rigidly attached to the shaft within the hollow portion, wherein a separation between an outer surface of the coolant feed tube and an inner surface of the hollow portion of the shaft defines a coolant flow region, a coolant being free to flow through the feed tube in a first direction and to flow through the coolant flow region in a second direction.

In various embodiments, the electric motor is an alternating current induction motor. Various embodiments of the vehicle further include a cooling subsystem to provide cooling to at least two zones, one of the zones including the battery. Various embodiments of the vehicle further include a processor to estimate a remaining operational time before depletion for the battery. Various embodiments of the vehicle further include a valve to regulate cooling of the zone including the battery, the valve controlled by the processor to cool the zone including the battery to maintain the battery below a threshold temperature until the battery reaches depletion.

The Abstract is provided to comply with 37 C.F.R. § 1.72(b) to allow the reader to quickly ascertain the nature and gist of the technical disclosure. The Abstract is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

1. A vehicle comprising:
   a battery to supply a flow of electrical energy;
   an electric motor arranged to propel the vehicle;
   a first control circuit coupled between the battery and the motor to control the flow of electrical energy to the motor;
   a first heat exchange loop thermally coupled with a heat exchanger including a heating element, the first heat exchange loop to circulate a first fluid to heat or cool a passenger cabin;
   a second heat exchange loop thermally coupled with the heat exchanger, the second heat exchange loop to circulate a second fluid to heat or cool the battery; and
   a second control circuit to couple a charger to the battery and to perform charging operations on the battery using a voltage source powered from a line source, the control circuit including a comparator circuit to register a difference between a battery voltage of the battery to a voltage of the line source, wherein the second control circuit is to couple the heating element between the voltage source and the battery
when the difference exceeds a predetermined voltage value, and to bypass the heating element when the difference is less than the predetermined voltage value.

2. The vehicle of claim 1, further comprising:
   a third control circuit constructed and arranged to control circulation of the first and second fluids, responsive to at least one parameter relating to the performance of the battery; and
   a battery monitoring device to measure a first temperature of at least one of a plurality of rechargeable cells within the battery, wherein the at least one parameter relating to the performance of the battery includes the first temperature.

3. The vehicle of claim 2, wherein the second heat exchange loop includes a cooling tube to be in thermal communication with at least one of the plurality of rechargeable cells, and the second fluid includes a coolant.

4. The vehicle of claim 3, wherein the third control circuit is to control a coolant temperature using a circulation of the coolant in the second heat exchange loop.

5. The vehicle of claim 1, further comprising:
   a third heat exchange loop to be in thermal communication with the first control circuit, wherein the first control circuit includes electronic circuitry to conduct the flow of electrical energy.

6. The vehicle of claim 5, wherein the third heat exchange loop is to further be in thermal communication with the motor and in thermal communication with a radiator.

7. A vehicle comprising:
   an electric motor to propel the vehicle; a battery including a first plurality of rechargeable cells coupled in parallel in a plurality of bricks to supply a flow of electrical energy to the motor;
   a first control circuit coupled between the battery and the motor to control the flow of electrical energy to the motor;
   a processor coupled to the plurality of bricks to identify at least one cell of the plurality of rechargeable cells that contains a weak short circuit and to deactivate such cells and to provide a weak short signal associated with the weak short circuit; and
   a further processor to be communicatively coupled to the plurality of bricks, the further processor to store a reference voltage for each brick and to sample at least one of the plurality of bricks for a first voltage and compare the first voltage with the reference voltage, the further processor to replace the reference voltage with the first voltage if the first voltage is lower than the reference voltage, and to cause the first voltage to be lowered if the first voltage is higher than the reference voltage.

8. The vehicle of claim 7, wherein the processor is to temporarily switch off cells of the plurality of rechargeable cells while monitoring the cells to detect a weak short circuit, and to determine that the at least one cell contains a weak short circuit when the at least one cell is switched off and the weak short circuit signal is detected.

9. The vehicle of claim 7, further comprising:
   a cooling tube including a first channel, the cooling tube to be thermally coupled with the battery, and to circulate a first flow of coolant via the first channel, to heat or cool the battery.

10. The vehicle of claim 9, wherein the cooling tube is to circulate a second flow of coolant, via a second channel, to heat or cool the battery, the first flow of coolant and the second flow of coolant to provide a flow of heat from one or more of the first plurality of cells, in opposing directions.

11. The vehicle of claim 9, wherein a first brick of the plurality of bricks includes a first conductor plate to be conductively coupled to at least one of the first plurality of rechargeable cells; and further comprising at least one fusible link to conductively couple the at least one of the first plurality of rechargeable cells with a first collector plate, the at least one fusible link to decouple from the first collector plate based on a detection of threshold current flow between the at least one of the first plurality of rechargeable cells and the first collector plate.

12. The vehicle of claim 11, further comprising a second brick of the plurality of bricks and a second collector plate to be conductively coupled to at least one of the plurality of rechargeable cells.

13. The vehicle of claim 12, wherein the first collector plate and the second collector plate are to be conductively coupled together in series via a fuse, the fuse to conductively decouple the first collector plate and the second collector plate based on a detection of a threshold current flow between the first collector plate and the second collector plate.

14. The vehicle of claim 12, wherein the first collector plate and the second collector plate are to be conductively coupled together via a flexible conductor.

15. The vehicle of claim 7, wherein at least one of the first plurality of rechargeable cells is coupled to a first conductor plate via a fusible conductor constructed and arranged to conductively decouple from the first conductor plate based on an exposure of the battery to at least one of a specified force, a specified vibration level and a specified thermal level.

16. The vehicle of claim 15, wherein the fusible conductor includes a wire made of an aluminum alloy.

17. The vehicle of claim 16, wherein the fusible wire has at least one of a specified thickness, a specified diameter or a specified length associated with at least one of a specific melting behavior and a specific fusing behavior.

18. The vehicle of claim 7, further comprising:
   a material to thermally couple with a case of each of the first plurality of rechargeable cells, the material having a higher thermal conductivity than air, wherein the material is to transfer heat released from a first of the first plurality of rechargeable cells to at least a second of the first plurality of rechargeable cells.

19. A vehicle comprising:
   a battery including a first plurality of rechargeable cells to supply a flow of electrical energy;
   a control circuit coupled to the battery, the control circuit to control the flow of energy; and
   an electric motor coupled to the control circuit to receive the flow of energy and to propel the vehicle, the electric motor including,
   a rotor assembly having a plurality of copper bar conductors embedded in a rotor surface, with some of the plurality of copper bar conductors being conductively coupled to one another, via a plurality of bridging copper slugs, and
   a rotor shaft having a hollow portion and a coolant feed tube rigidly coupled to the shaft to communicate with the hollow portion, wherein a separation between an outer surface of the coolant feed tube and an inner surface of the hollow portion of the shaft defines a coolant flow region for coolant
flowing through the feed tube in a first direction, and to
flowing through the coolant flow region in a second
direction.

20. The vehicle of claim 19, wherein the electric motor is an
alternating current induction motor.

21. The vehicle of claim 19, further comprising:
a cooling subsystem to provide cooling to at least two
zones including the rotor shaft, at least one of the zones
including the battery;
a processor to estimate a remaining operational time before
depletion of the battery charge; and
a valve to regulate cooling of the zone including the rotor
shaft, the valve controlled by the processor to cool the
zone including the rotor shaft to maintain the rotor shaft
below a threshold operating temperature until the bat-
tery charge reaches depletion.

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