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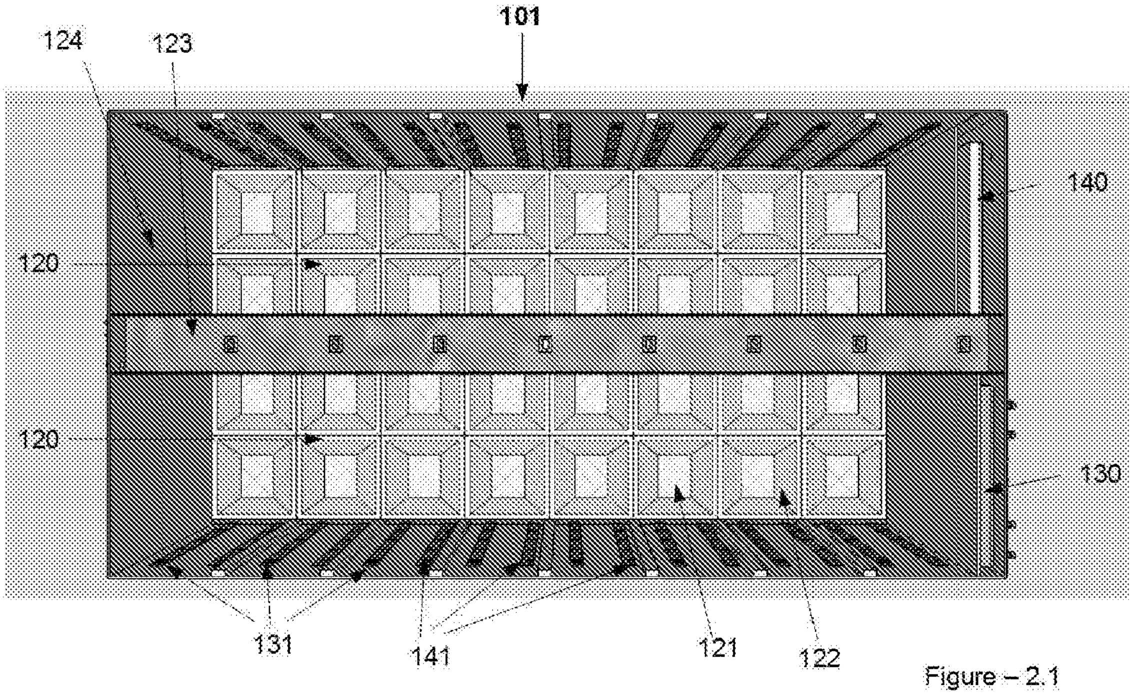

Figure – 2.1

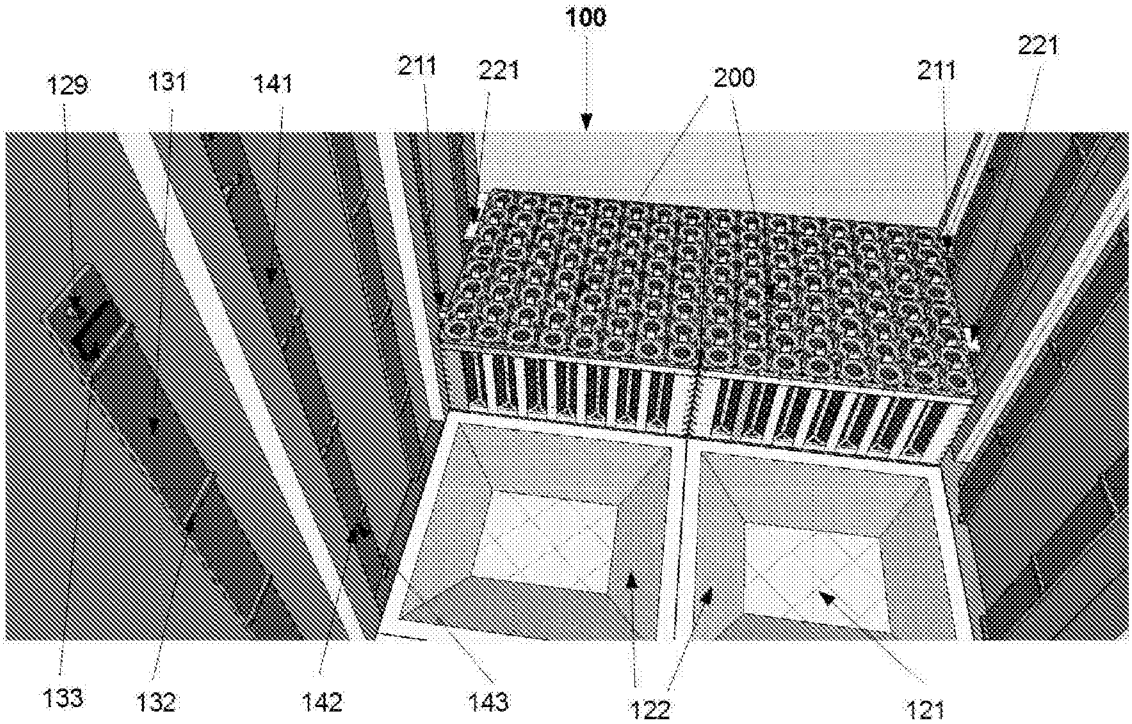

Figure – 2.2

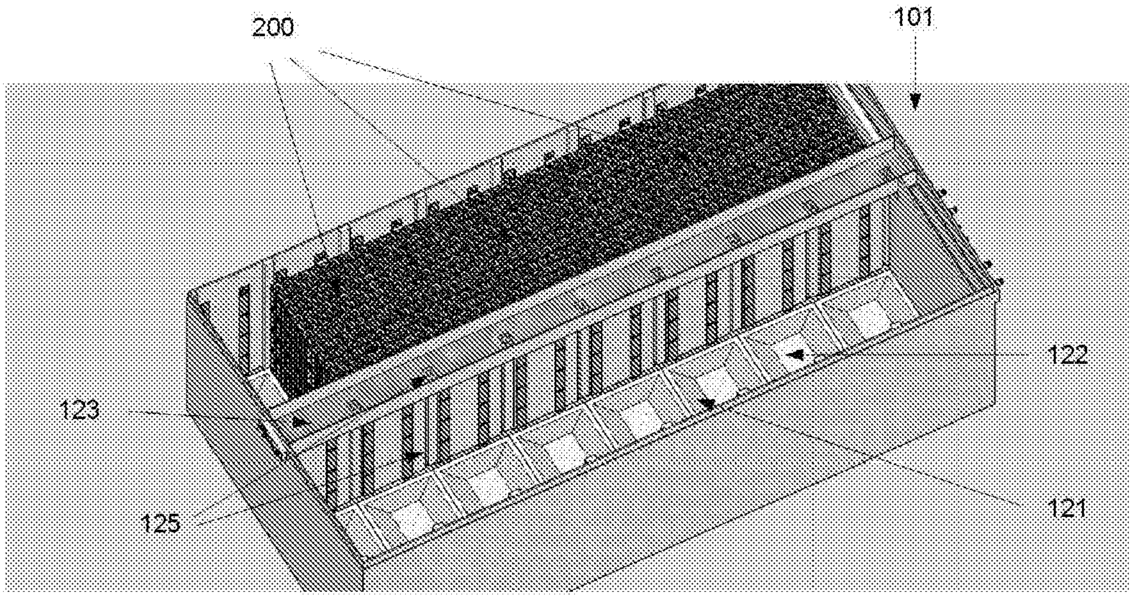

Figure – 2.3

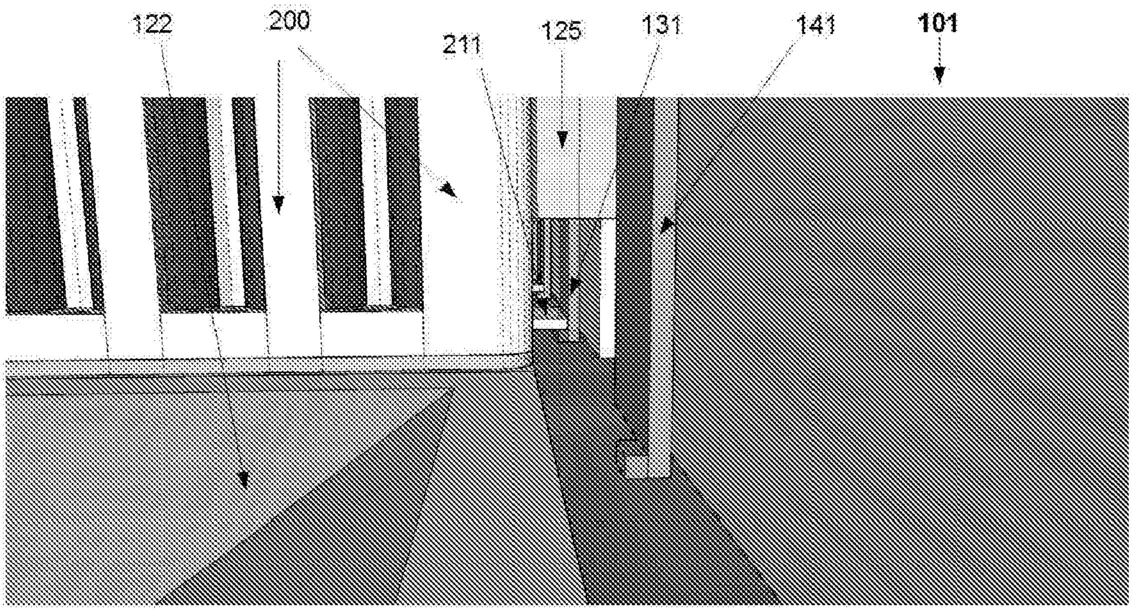

Figure – 2.4

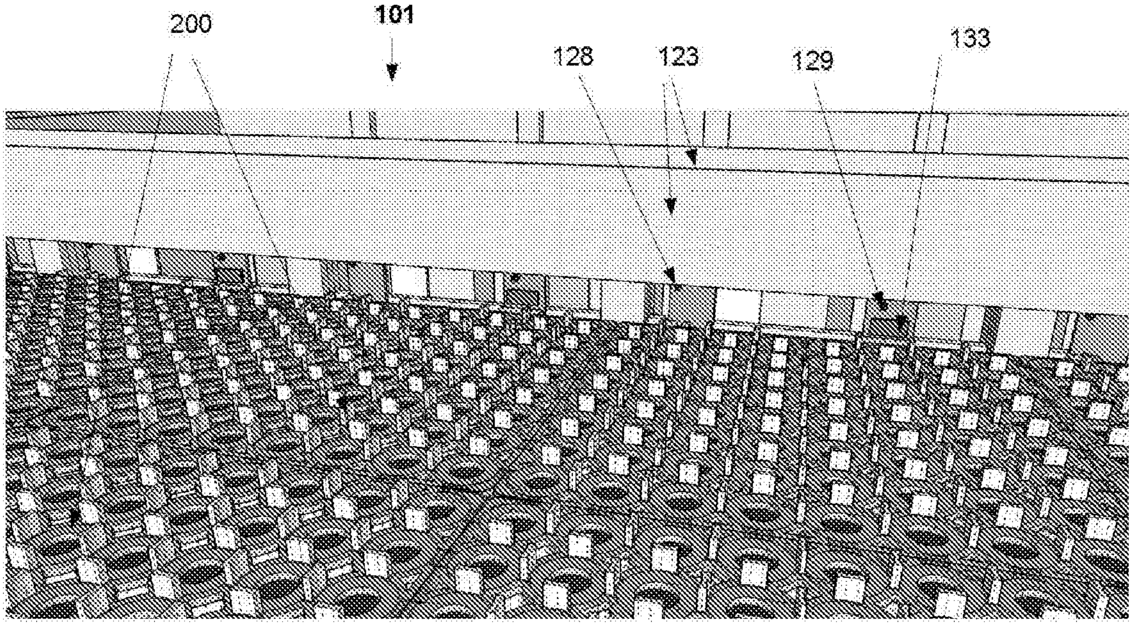

Figure – 2.5

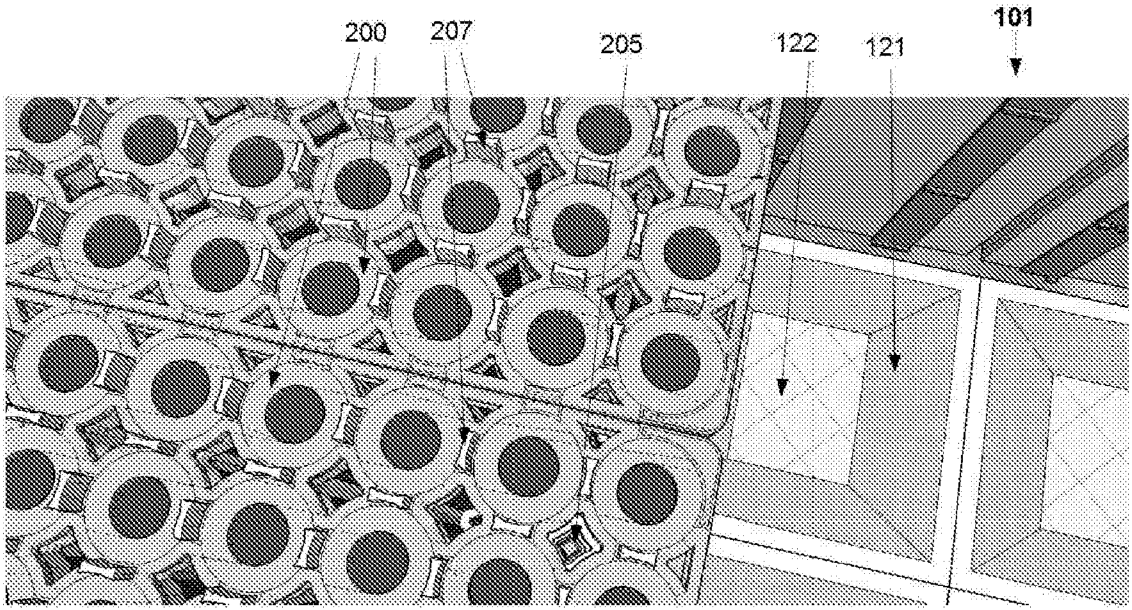

Figure – 2.6

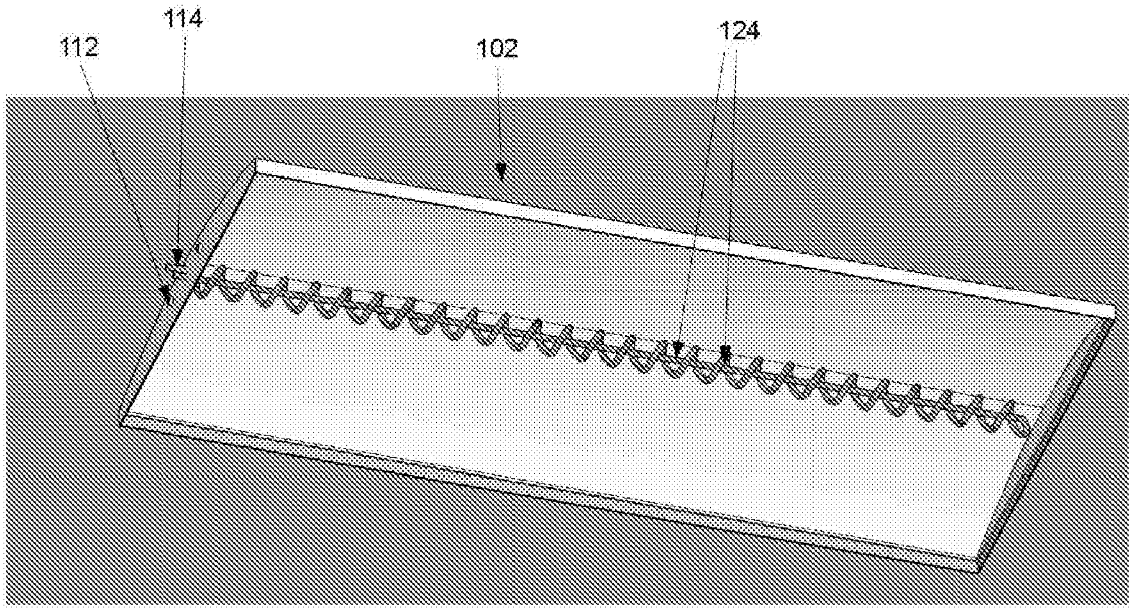

Figure – 2.7

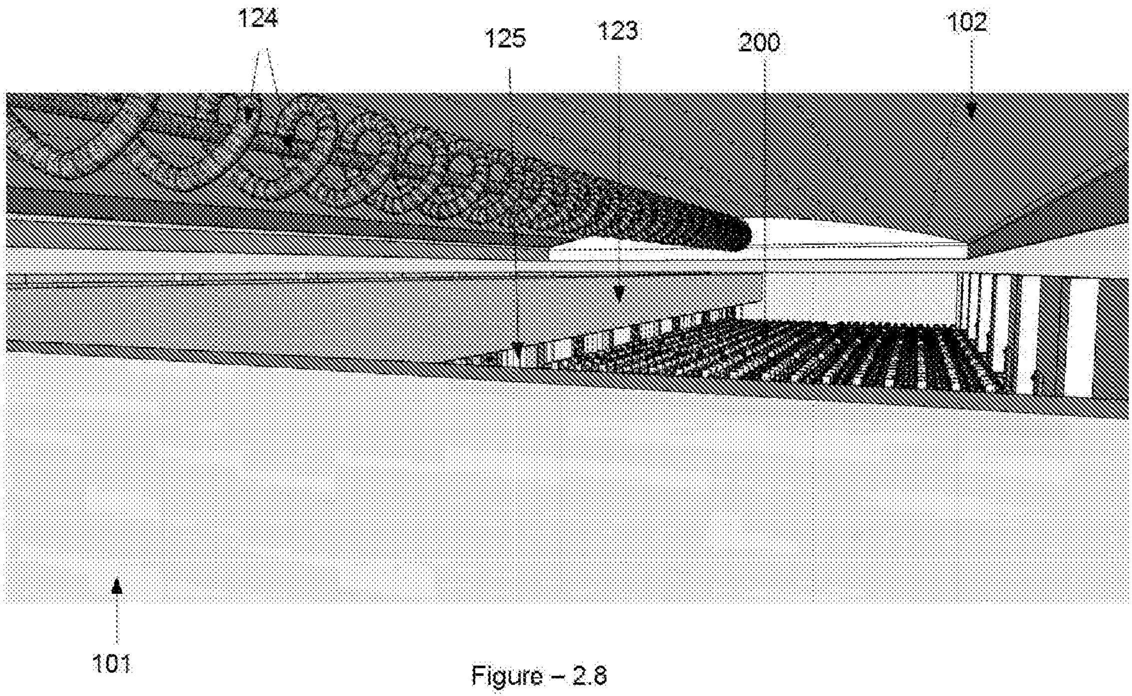

Figure – 2.8

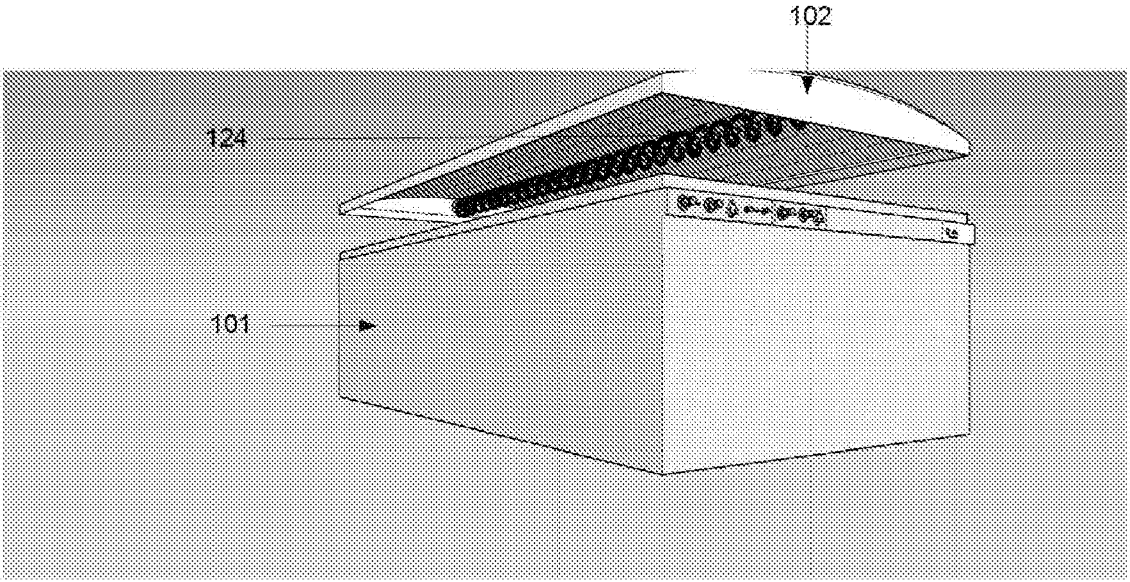

Figure – 2.9

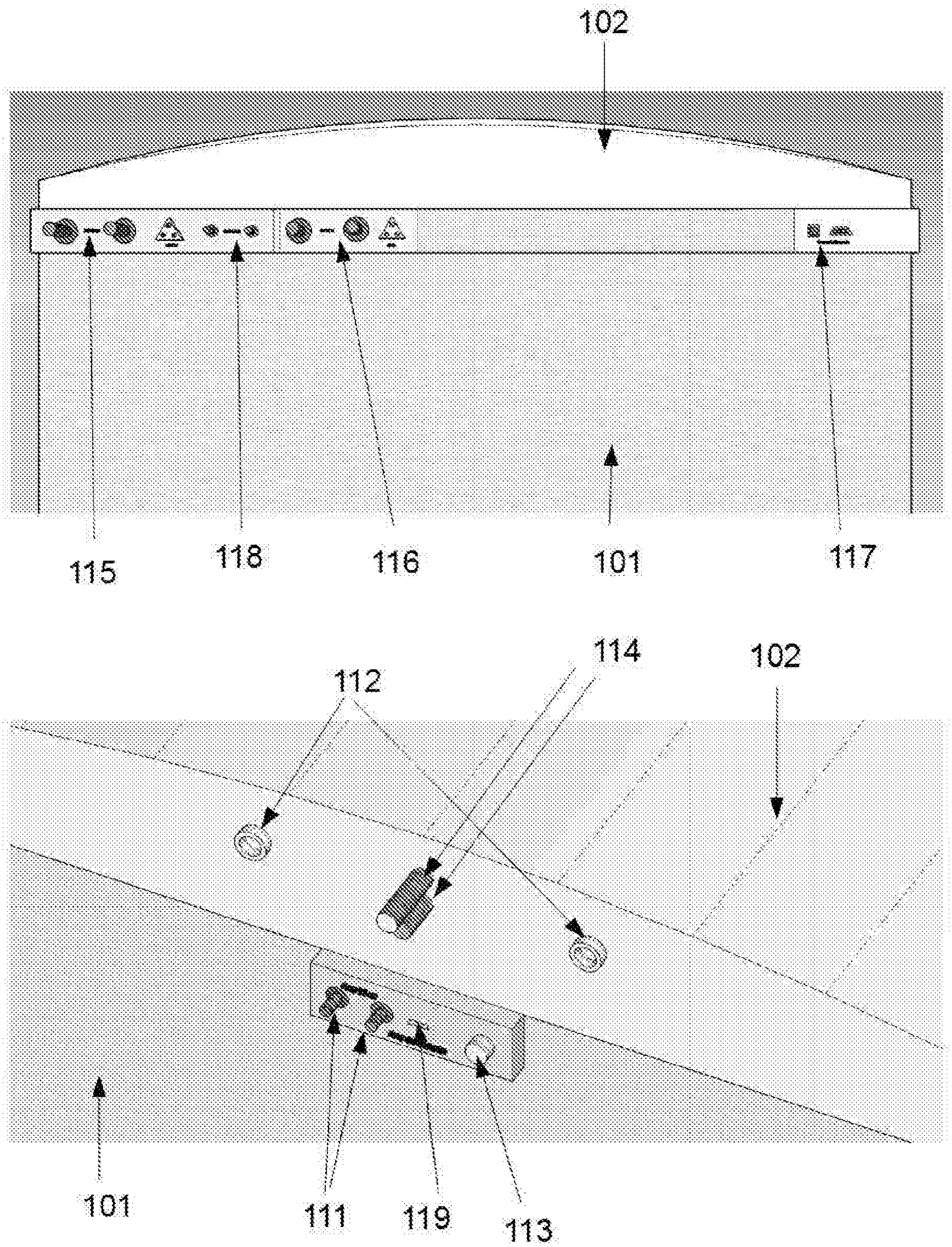

Figure – 2.10

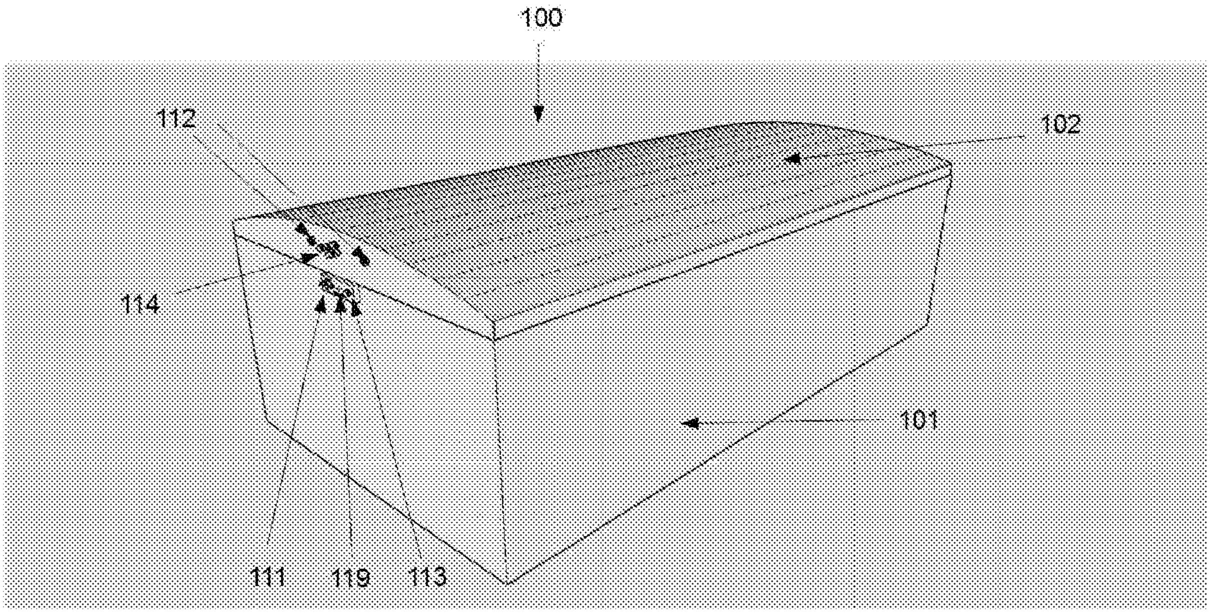

Figure – 2.11

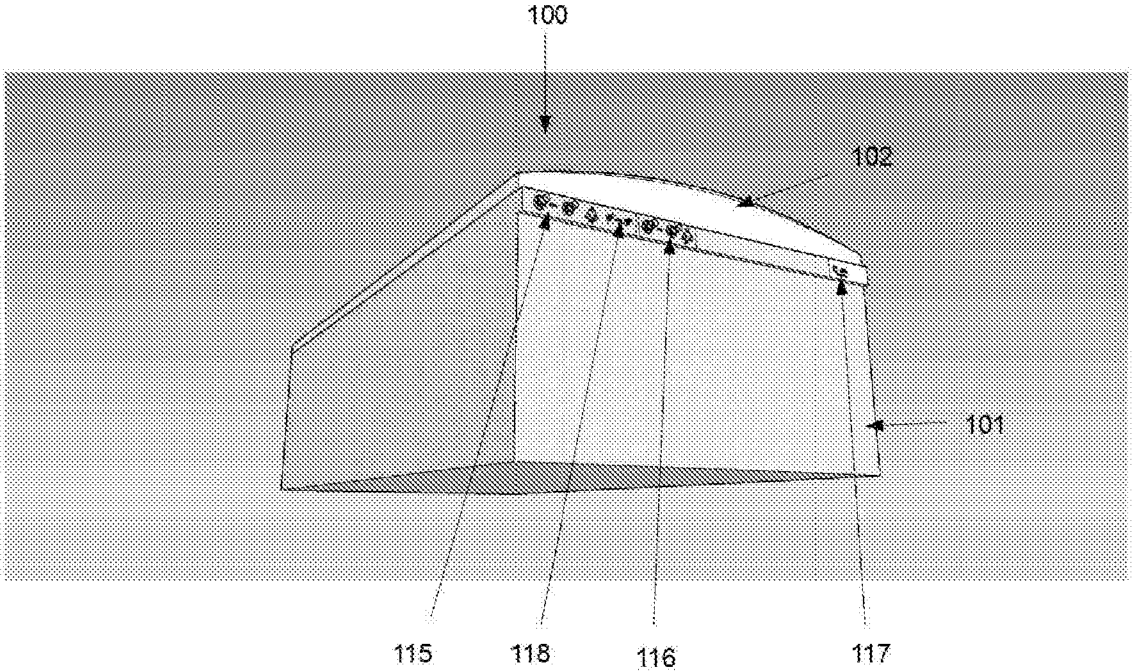

Figure – 2.12

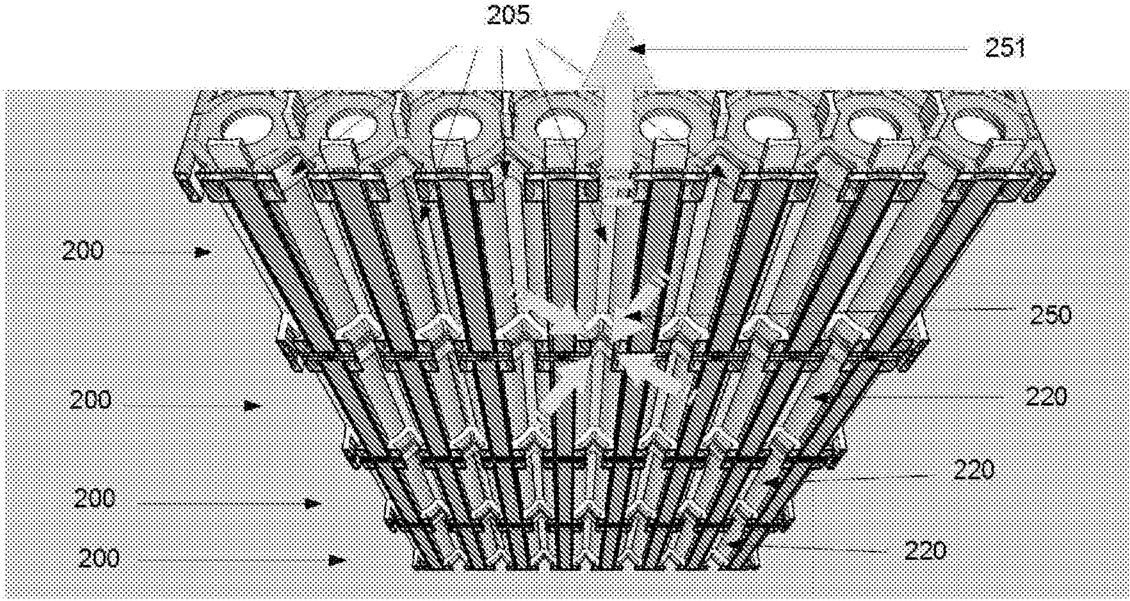

Figure – 1.12

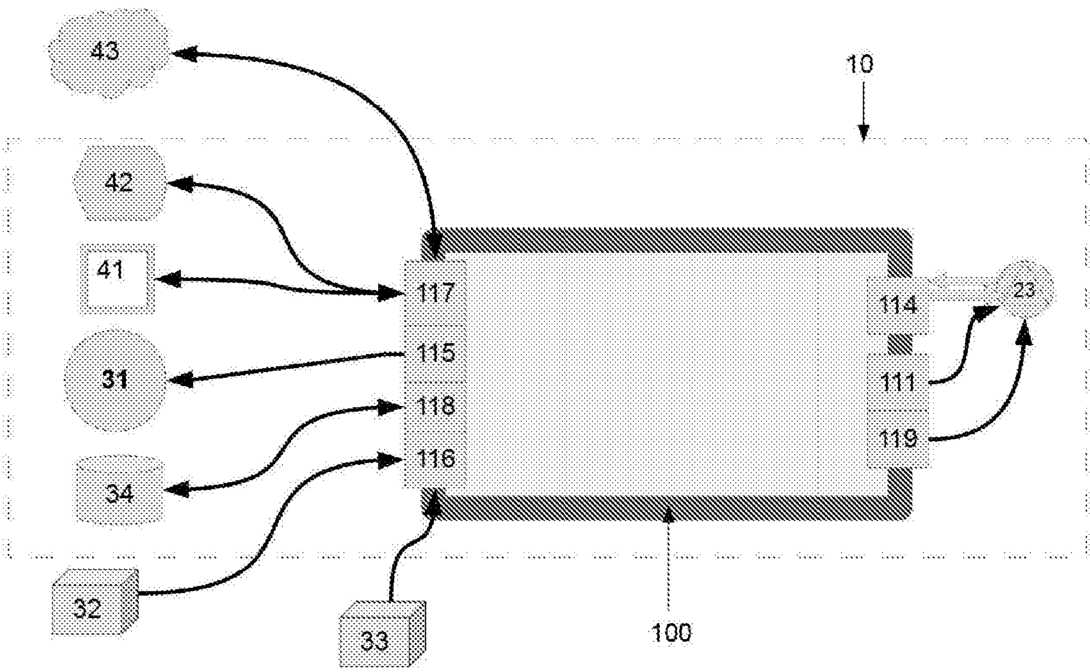

Figure – 3

The following terms are registered trade marks and should be read as such wherever they occur in this document:

iPhone
Samsung

Description:

Title of description

A Method of protecting a large battery pack from thermal stresses

Technical Field

Battery packs used in large electric vehicles e.g. cars, trucks, buses, vans, trains, boats to supply high voltage power to electric motors. This invention relates to large battery pack technology.

Background information

Vehicles use ICEs to power its drive train. For electric vehicles a battery pack is needed to supply large power to electric motors.

Rechargeable batteries e.g. lithium Ion batteries, which are the building blocks of a battery pack, take long time to charge and have very narrow safe operating temperature and charging temperature range, depending upon its chemistry. Batteries generate heat during normal operations (discharging) and charging (depending upon the battery balancing method deployed). Batteries produce even more heat during peak usage (when max current demand is placed on the battery pack), or when the battery is charged using large current as in the case of super/fast chargers. In real world electric cars, trucks, buses, vans, trains, boats or backup power unit for hospitals, data centres and industrial units, have to operate in wide ambient temperature range e.g. from minus 40° C to over 60° C. Ambient temperatures also put thermal stresses on the batteries during usage and even when the batteries are not being used.

Large commercial vehicles also have to operate in rain and sometimes low level flooded areas, especially boats have high chance of exposure to water. Large battery packs including its electronics should be waterproof or water-resistant.

Thermal management:

Air Cooling - Simple battery packs deploy air cooling, which uses gaps between the batteries, to circulate the air to cool the batteries during operations and charging.

Benefits of air-cooling:

1. It's cheaper to install, as no pumps are required.

Drawbacks of air-cooling –

1. this limits their usage under ambient temperatures outside the normal range,
2. this limits the energy density (energy density for a given cubic metre space) that can be achieved.
3. In the event of small flooding, it can lead to short circuit and permanent damage to the battery pack and associated electronics.
4. Typically the batteries are hard wired. In the event of an accident the fire rescue team has to isolate the battery from rest of the vehicle to safely rescue the occupants.

Cooling Tubes/leaves - Sophisticated battery packs use cooling tubes, which are in direct contact with the battery's sides to cool and heat the batteries. High pressure pumps push cooling/heating liquid through very narrow tubes/leaves interleaved with the batteries, to maximise the energy density and maximise the surface contact area with the batteries. The energy required to cool/heat the battery pack increases as the ambient temp moves away from the safe operating temp of the batteries.

Benefits of the cooling tubes:

1. This provides the higher energy density compared to the air-cooled battery packs.
2. The pack can be used in wider ambient range compared to air-cooled battery packs.
3. The pumps consume small enough energy (compared to the stored energy in the battery pack) to push the cooling/heating liquid around the pack, during the normal ambient temperatures and normal usage of the battery pack.

Drawbacks of cooling tubes:

1. In extreme (temperature below zero and temperatures above 40° C) ambient temperatures, high pressure pumps have to push large amount of the cold or hot liquid through narrow tubes/leaves, and consume a significant amount of energy (compared to the stored energy) to cool/heat the battery pack.
2. There is a an uneven cooling or heating of the pack, as batteries close to the inlet are better cooled or heated, vs. the ones close to the outlet.
3. If one or more of the batteries in the battery pack, get into thermal runaway (uncontrolled heating) which can also lead to fire in the battery pack; it's very difficult to cool the individual batteries and extinguish the fire. Secondary technologies e.g. fuses are deployed to stop the thermal runaway. A separate technology is needed to put out the fire.
4. In the event of small flooding, it can lead to short circuit and permanent damage to the battery pack and the associated electronics.
5. Typically the batteries are hard wired within the battery pack as high power switches produce a lot of heat in close proximity of the batteries. In the event of an accident the fire rescue team has to electrically isolate the battery from rest of the vehicle, to safely rescue the occupants.

Flood protection:

The air cooling and cooling tubes thermal management, is not water resistant or offer protection from high voltage when the vehicle is fully or partly submerged, and it does not create a water resistant battery pack for all its batteries and the associated electronics. Flooding can result in significant damage to the battery pack, and there is a risk of exposure to high voltages.

How this invention solves the technical problems, and how it is different

This invention solves the current technical problems through many innovative steps:

1. Thermal management – This innovation uses dielectric liquid with a low boiling point as a carrier of heat from individual batteries/capacitors and the associated electronics in the BTBT to the condenser. Batteries are packed inside modules and the modules are stacked horizontally and vertically inside the BPBT. The dielectric liquid which is two phase (liquid-

vapour) comes in direct contact with the batteries, the connectors, and the associated electronics. This invention has created vertical ducts in between the batteries. Bubbles are created when subcooled liquid comes in contact with the hot batteries. The bubbles are then channelled into the vertical ducts; these bubbles produce vertical flow of 2 phase dielectric liquid and vapours inside the ducts. These ducts act as heat exchangers. The process of subcooled flow boiling process cools the batteries. This vertical flow also creates low pressure inside the ducts and this creates localised a horizontal movement of liquid, cooling from its tabs.

2. Charging and discharging of batteries in extreme temperatures – In addition to batteries this innovation uses capacitors to store energy, which is used to heat the dielectric liquid in the extremely cold temperatures e.g. -40 degree Celsius. From -40 degree Celsius to zero degree Celsius, it's not possible to charge or discharge the lithium ion batteries without damaging its life, capacitors heat up the dielectric liquid to bring the batteries temperature to the safe operating temperature. In extremely hot temperature of 45-60 degree Celsius, especially the tarmac temperature, capacitors supply power to the pump to circulate refrigerant/water through the condenser to cool the BPBT.
3. Water resistance – This innovation make the whole of BPBT a water-tight bath tub, which houses the batteries, the electrical wiring, the electronic circuitry to control the BPBT, and the power electronics to charge the BPBT .
4. Modular design – This innovation allows the extension and reduction of the capacity of the BPBT.

Brief about Drawings

- Figure 1.12 – shows the ducts (205) of all the vertical stacked BMs (200) are aligned to form vertical ducts (205) and vertical flow of dielectric liquid
- Figure 2.1 to 2.12 – show the details of the Battery Pack Bath Tub(100)
- Figure 3 – Schematic diagram of BPBT (100) external connections. It shows how BPBT connects to various components in an electrical vehicle (10).

Detailed description of preferred embodiment, and how it is manufactured

The inventions will be explained through preferred examples of Battery pack bath tub (100).

The aim of this invention is to design a method for a battery pack BPBT(100), which creates:

a. highly controlled and homogenous temperature environment for cooling the batteries in hot and extremely hot ambient temperatures, that extends the life of the batteries and capacitors;
b. highly controlled and homogenous temperature environment for heating the batteries in cold and extremely cold ambient temperatures, that extends the life of the batteries and capacitors;

c. modular serial and parallel electrical circuitry so that any number of modular cases can be fitted electrically in serial and/or parallel, inside the battery pack;
d. modular communications with the modules, so that a module with a given ID can be located anywhere in the container (101);
e. modular mechanical fittings so that modular cases can be horizontally and vertically stacked for maximum energy density;
f. highly controlled and homogenous temperature environment for all the associated electronics of the battery pack;
g. safety from fire and gases in the event of thermal runaway of a battery or a number of batteries;
h. safety from flooding for the batteries, capacitors, electrical circuitry and the associated electronics;

i. minimum power consumption of external pumps and the amount of external liquid/refrigerant needed to be cooled/heated and circulated through the BPBT;
j. make the batteries last higher number of charge cycles.

Figure 2.1 shows the shape of the base of the BPBT (100) is a rectangle; however in another embodiment it can be a polygon or a circle. In another embodiment it could be shaped to fit into a specific space available in the vehicle. In this disclosure all these shapes and types of containers are referred to as a container (101).

Figure 2.1 and figure 2.2 shows, in this embodiment the BPBT is a large bath tub like container (101) filled with 2 phase (liquid and vapour) dielectric liquid, and following are all immersed in the dielectric liquid:

a. Plurality of Battery module BM (200) where each module is packed with plurality of rechargeable batteries (220) and capacitors(220);
b. Power board (130) to charge large number of rechargeable batteries;
c. Battery pack controller board (140);
d. Relay switches (133).

Last three items in the above list are optional. In one embodiment Power board (130) can be located outside the container or the BPBT, and may not be part of the electronics of the BPBT. In another embodiment parts of the power board can be inside the BPBT and rest can be outside the BPBT. In another embodiment, Battery pack controller (140) can be implemented outside the BPBT and may be called battery management system (BMS). In further embodiment battery pack controller (140) may be part of the BPBT but located outside the container. In one embodiment Relay switches (133) can be located outside the container. In another embodiment one or more relay switches can be located inside the container and rest outside the container or in further embodiment all of the relays switches can be located outside the BPBT.

In this disclosure, the dielectric liquid is a thermally conductive but electrically insulative liquid e.g. flurocarbons. In this particular embodiment the dielectric liquid chosen is of low boiling point which is lower than the maximum operating temperature of the batteries (220) and capacitors (220), which when comes in contact with hot batteries/capacitors (220) produces bubbles and the dielectric liquid is also heated by convection. In another embodiment a combination of pressure inside the battery pack (101) and the high boiling point of the dielectric liquid can be used, to achieve a higher boiling point of the dielectric liquid inside the battery pack (101) e.g. if the BPBT is used at high altitudes, it would lower the boiling point of the dielectric liquid, the battery pack (101) can then be pressurised to increase the boiling point of the dielectric liquid inside the battery pack (101) or dielectric liquid can be chosen which has higher boiling point than the maximum operating temperature of the batteries (220) and capacitors (220).

Mechanical arrangement of BM(200) inside the BPBT(100)

BPBT (100) allows a mechanical as well as electrical flexibility in choosing the mechanical size/shape of the BM(200), e.g. square or rectangle or any polygon, and how many batteries and capacitors are connected electrically in series or parallel inside a BM(200). BPBT(100) also gives flexibility in choosing how these BMs(100) are mechanically and electrically arranged inside the BPBT in terms how many BM that can be stacked horizontally or vertically inside the BPBT, and how many BMs are electrically connected in series and how many BMs are connected in parallel. Further BPBT(100) gives flexibility in terms how many BMs that can be mechanically and electrically fitted inside the BPBT.

As shown in figure 2.1, 2.2 and 2.3, in this embodiment, BPBT (100) has configuration of 128S64P, (128 series and 64 parallel). It has 128 BMs (200), with 62 batteries and 2 capacitors in each BM. It has mechanical layout with 32 BMs(200) (4 rows of 8 BMs) laid horizontally, and 4 BMs are stacked vertically in each column. In another embodiment, it can be a mechanical layout with any number of horizontally laid and vertically stacked BMs(200), depending upon the energy requirements of the application and the space available in the application e.g.160S256P configuration can be implemented in 80 modules and each BM with a electrical configuration of 2S256P (2 vertical layers and each layer has 248 batteries connected in parallel and 8 capacitors connected in parallel); has a mechanical layout of 16 BMs x 5BMs (16BMs are laid horizontally and 5 BMs are stacked vertically in each column); and all the BMs are electrically connected in series inside the BPBT. In a preferred embodiment, the same electrical configuration of 160S256P can also be implemented in 640 modules; and each module has a configuration of 64P (62 batteries connected in parallel and 2 capacitors connected in parallel); has mechanical layout of 64 BMs x 10BMs (64 BMs are laid horizontally, and 10 BMs are stacked vertically in each column); 160 sets of BMs are connected electrically in series and there are 4 BMs connected in parallel in each set.

In this disclosure, the combination of batteries and capacitors is optional. The BM(200) can be created just with batteries. The BM(200) can also be created just with capacitors.

Electrical serial connection in this disclosure means when positive ends of a group of battery are electrically connected to the negative ends of another group of batteries, the two groups of batteries are said to be connected electrically in serial fashion.

Electrical parallel connection in this disclosure means when positive ends of a group of batteries are electrically connected to the positive end of another groups of batteries, and the negative end of the first group of batteries are connected to the negative ends of the second group of batteries, the two groups of batteries are said to be connected electrically in parallel fashion.

Electric connections inside the BPBT

As shown in Figure 2.2, in this embodiment of BPBT(100), BMs(200) are electrically serially connected via HV terminals (132) provided on the PCB (131). BMs(200) are charged through charging terminals (142) provided on the PCB (141). The battery pack controller (140) communicates with the BMs(200) through communication terminal (143) provided on the PCB (141).

In this embodiment the battery pack controller is installed inside the battery pack, however in another embodiment it can be installed outside the battery pack(100).

In this embodiment the BPBT (100) has electrical configuration of 128S64P (128 series and 64 parallel). It has 128 BMs (200), with 62 batteries and 2 capacitors in each BM(200). Each battery inside a BM is of nominal voltage of roughly 3.65v and roughly 3.4aH capacity, this makes the total capacity of the battery pack (ignoring the energy of capacitors) = 128*62*3.65*3.4 = 98KW, which is capable of powering a SUV, a van or light commercial vehicle.

In this particular embodiment BM has 62 cylindrical lithium-ion (Li-ion) rechargeable batteries (220) and 2 capacitors. In another embodiment it could be any other chemistry; in the shape of cylinder, tower, pouch or prismatic or any other shape. In this disclosure all these rechargeable batteries (220) of different chemistries and shapes are referred to as Batteries (220) in plural and Battery in singular. In this particular embodiment BM has 2 Electric double layer capacitors (EDLC) cylindrical capacitors, also called supercapacitors. In another embodiment these capacitors could be Asymmetric Electrochemical Double Layer Capacitor (AEDLC), Lithium Ion capacitors, or graphene supercapacitors. In this disclosure all capacitors of different electrochemical, chemistries and shapes are referred to as capacitors in plural and capacitor in singular. In another embodiment there could be any number of batteries (220) and any number of capacitors (220) in a BM.

In another embodiment, the configuration can be xSxP, the voltage requirement of the embodiment determines the number of electrically serially connected batteries; and current requirement of the embodiment determines the total number of parallel batteries to be connected e.g. configuration of 160S256P; it has 160 BMs, with 248 batteries and 8 capacitors in each BM; using the same batteries will produce (ignoring the energy of capacitors) = 160*256*3.65*3.4 = 508KW, which can be used to power lorries and boats.

In this embodiment, electrical HV terminals (132), charging terminals (142) and communication terminals (143) are arranged, inside the BPBT, as per the electrical configuration of 128S64P. In another embodiment, the BPBT with electrical configuration of 160S256P with 160BMs with each BM of configuration 256P, has 160 HV terminals (132), 160 charging terminals (142) and 160 communication terminals (142). However, in another embodiment, the same electrical configuration of 160S256P can be implemented using 640 BM(200) with each BM of configuration 64P, the BPBT will have 640 HV terminals (132), 640 charging terminals (142) and 640 communication terminals (142).

How thermal stresses are managed inside BPBT(100)

Figure 2.3 shows in this embodiment, a trough (123) with a cross-section of a square, collects the condensate, and vertical drain pipes (125) deliver the subcooled condensate to the sump (122). In another embodiment a trough with a cross-section of funnel or semicircular or half oval or any polygon, can be used to collect the condensate. In this disclosure all such shapes of troughs are referred to as trough. In another embodiment where there are more than one condensing coils (explained further down), there can be more than one troughs to collect the condensate. Another innovation here is that a combination of a trough (123) and vertical drain pipes (125) are used to deliver the condensate at the bottom of the BMs. Further innovation is that the trough (123) provides structural strength at the top of the container (101) and drain pipes (125) create a mechanical separation between two rows of BM(200).

Figure 2.2 and figure 2.3 show a square sump (122) which matches in size with the base of module BM (200) such that there is one sump for each column of BMs. In another embodiment the shape of the sump can be of any polygon and each sump may service more than one column of BMs. In this disclosure all such shape and size of sumps are referred to as sumps. The sumps (122) collect the dielectric liquid which can be heated using the PCT heater (121). The heater can be any coil heater or heating tubes through which hot water is circulated. In this disclosure all such heaters are referred to as Heater.

The battery pack controller (140) is electronically connected to the heater (not shown) to control its functions e.g. switches on the heater when the temp inside the container (101) falls below minimum allowed by the chemistry of the batteries; switches off the heater when the temperature inside the container (101) has reached a preset level.

Figure 2.4 shows that the vertical drain pipe (125) delivers the subcooled condensate, at the base to fill the sumps (122). Figure 2.4 also shows that BMs(200) sit on top of sump (122).

Figure 2.5 also shows that when all the BMs(200) are stacked inside the battery pack container (101), these are level and the dielectric liquid fills the container (101). The figure 2.5 also shows the relay switches (133) attached to the top of the PCB (131), and are immersed in dielectric liquid. The relays (133) switch off the serial circuit inside the container (101) such that when the electric vehicle is switched off the system voltage is less than SELV (Safety extra low voltage) level, and also bypass a BM or group of BMs, as per the control signals from the battery pack controller (140). There are various standards of SELV, the voltage of 60v is considered as SELV in this disclosure. In another embodiment the relay switches (133) can be attached anywhere on the PCB (131). The relays (133) are optional. In another embodiment the relays (133) may not there. In this disclosure relay switch (133) means a switch e.g. FET, MOSFET etc.

In figure 2.5 pressure sensor (129) measures the pressure inside the container (101). Battery pack controller (140) electronically connected to the pressure sensor (129), records the pressure inside the BPBT(100) at all times.

In this disclosure electronic connection means when two devices communicate with each other through electronic (digital or analogue) signals e.g. electronic connection between battery pack controller (140) and a sensor or electronic connection between battery pack controller(140) and battery charge controller (240).

Battery pack controller (140) is electronically connected to a gas solenoid (113) as shown figure in 2.11. Battery pack controller (140), opens the gas solenoid (113) if the pressure inside the container (101) is higher than preset level, to release the pressure and gases inside the container (101) and closes the solenoid valve after the pressure reaches a preset level.

Figure 2.11 shows the Immersion proof breather (112), which is a pressure balancing device(balances the pressure inside the container (101) and outside the container (101)), works even when the container (101) is fully submerged (for safety reason, the design allows temporarily fully submerged container (101)). Immersion proof breather are optional, e.g. if the battery pack is used in high altitude areas, pressure inside the container (101) is deliberately maintained at higher levels than external pressure. This is done so that dielectric liquid's boiling point does not fall below a preset level. Immersion proof breathers (112) may also be omitted in areas where these may not work properly e.g. in desert/sandy areas or where these let in extreme ambient temperatures through its membranes.

Optional Liquid level sensors (128), as shown in figure 2.5 measure the level of the dielectric liquid inside the container (101). Battery pack controller (140), electronically connected to the liquid level sensor, monitors the dielectric liquid level inside the container (101) using these sensors, and alerts the user of the battery pack to top the dielectric liquid if the level of the dielectric liquid inside the container (101) is lower than the preset level. In another embodiment these sensors can be placed anywhere inside the container (101). In further embodiment there may not be any liquid sensor.

In this embodiment Battery pack controller (140) checks the temperature inside the BMs, and if it is hotter than the optimum operating temperature range of the chemistry of the batteries e.g. 35 degree Celsius, then Battery pack controller switches on the pump (23) as shown in figure 3 or increases the flow rate of the liquid/refrigerant through the condenser (124) to cool the vapours faster by increasing the speed of the pump (23). If however the measured temperature is cooler than the optimum operating range of the chemistry of the batteries e.g. less than 10 degree Celsius, then Battery pack controller (140) switches on the heater (121) to heat the dielectric liquid. Thermal insulation is also used to protect the container from the extreme temperatures.

How vertical stacking of BM(200) work inside the container(101) :

Figure 1.12 and figure 2.6 shows, when the BMs (200) are vertically stacked, the ducts (205) of all the vertical stacked BMs (200) are aligned to form vertical ducts (205). The separators (207) of each BM (200) are used to vertically align the BMs(200).

The vertical flow starts at the bottommost BM(200) and travels through the 4 vertically stacked BM(200) in this embodiment, inside the ducts(205), until the dielectric liquid and the bubbles reach the surface of the liquid inside the container (101). In another embodiment there could be more or fewer vertically stacked BM(200). The vertical flow continues through the stacked BM(200), inside the ducts (205), until it reaches the surface of the dielectric liquid. As shown in figure 1.12, the vertical flow (251) of dielectric liquid also creates a low pressure inside the ducts (205), and low pressure creates a localised horizontal flow (250) of liquid towards the ducts; and the low pressure sucks in hot liquid from the gaps in between the stacked BM(200), which in turn sucks in hot liquid from the tabs of the batteries; harnessing the effects documented in Bernoulli's theorem.

One of the innovation here is the BPBT is mechanically designed which allows horizontal and vertical stacking of BMs. Vertical heat exchanging ducts (205) which are formed by stacking the BMs allow vertical flow of dielectric liquid through the BMs, which allow the vertical ducts to act as heat exchangers. Further electrical circuitry is also designed such that any number of BMs can be electrically connected in serial or parallel manner inside the container (101) and further electronic communication terminals available on PCB (141) are also designed for the BMs such that battery pack controller can communicate with a BM, regardless where a BM with specific ID is located inside the container (101).

As shown in figure 2.7 and figure 2.8, in this embodiment helical coil (124) is used as a condenser to maximise the cooling surface area in a confined space, and parabolic lid (102) is used to channel the vapours towards the cooling coil. In this embodiment there is one helical coil (124) to condensate vapours from 4 rows of BMs(200), in another embodiment there could be two or more helical coils (124) attached to the lid (102) to condensate 8 or more rows. In another embodiment a cooling plate can be used as a lid. In another embodiment curled/straight pipes fitted to the lid can be used as a condenser. In another embodiment microfilm can be attached to the lid with cold liquid inlets and outlets. In another embodiment high grade refrigerant is circulated through the cooling tubes instead of water/glycol. In further embodiment the vapours can be siphoned out of the container (101), condensed using an external cooling loop, and returned to the container (101). In this disclosure any of the above types of condensers is referred to as a condenser. Thermally connecting the container to a condenser in this disclosure means connecting the container to a condenser where condenser is either fitted inside the container or a condenser which is fitted outside the container. Returning the condensate directly to the base of the container in this disclosure means the condensate is delivered to the base of the container e.g. by using troughs where the condenser is fitted inside the container; or directly from the condenser to the base of the container where the condenser is fitted outside the container.

Another innovation here is that a combination of helical coil (124) and a parabolic lid (102) is used to maximise the condensation efficiency as well as ease of manufacturing and maintenance of coil (124) and the lid (102). Further innovation is the external shape of a parabolic lid (102) helps to drain away the water if the BPBT(100) is exposed to rain or splash of water, and contributes towards the innovation of making the battery pack flood proof.

Flood proof in this disclosure means that the battery pack's internal circuit and batteries are not impacted by splash of water, though not fully submerged.

Figure 2.9 shows how the lid (102), slides into the container (101) and sealed with a waterproof sealant to create a watertight BPBT(100). Watertight in this disclosure means it does not let water in when exposed to splash of water but not fully submerged. Waterproof sealant in this disclosure means a sealant that does not wash away when exposed to water. Another innovation here is that all the batteries and the associated electronics is contained inside the watertight BPBT(100). In another embodiment however part of the associated electronics can be located outside the container (101) e.g. Power board can be located outside the container (101).

Another innovation here is that a sealed container consisting of all the batteries, electrical circuits, associated electronics, with a thermal management is used to achieve flood proofing of the BPBT(100).

Associated electronics in this disclosure means, the electronics to charge, discharge, and manage the battery within safe thermal limits and manage the overall functions/communications of the battery pack, e.g. Power board with AC/DC converter, Dc-DC converter; battery monitoring board, battery charge controller etc.

Figure 2.10 shows, in this embodiment, the helical coil (124), has a water/refrigerant inlet and outlet (114). The gas solenoid (113) can be used to top the dielectric liquid.

How the BPBT(100) is electrically or electronically connected to the EV(10) and external chargers

Figure 3 is a schematic diagram of particular version of how the BPBT (100) fits into an electric vehicle (EV) (10). In this particular embodiment, as shown in figure 2.12 and figure 3, the BPBT (100) has a high voltage DC output port (115) with positive and negative terminals which can be electrically connected to electric motor/s (31) positive and negative terminals of electric vehicle (10). In another embodiment there could be two or more DC output ports (115) available on BPBT connected to two or more electric motors (31). As shown in figure 2.12 the port (115) also has an AC output port which can be electrically connected to any AC consuming device (not shown) e.g. AC supply to a house or any other AC motor/device. This AC port is optional. In another embodiment e.g. when used as a backup battery for a house/office just the AC output port is there and DC output port is either optional or not supplied. In figure 2.10 and 2.12, the high voltage DC output port (115) shown here as a straight connector, in another embodiment a different connector compatible with a particular manufacturer's cable can be used with harnesses. In figure 2.10 and 2.12 the AC output port (115) shown is a single phase wall socket, in another embodiment it can be a three phase AC connector, compatible with a particular manufacturer's cable with harnesses.

In figure 2.12 and figure 3, in this particular embodiment the BPBT is shown with a high voltage DC input port (116) with positive and negative terminals connected to a street based DC charger's (32) positive and negative terminals. In another embodiment there could be an additional DC input port which allows charging to a different voltage level e.g. one DC input port allows 200V-400V DC and the second port allows 400V- 600V charging. In figure 2.12 and figure 3, the port (116) also has an AC input port which is electrically connected to any AC charging terminal (33) e.g. home or street based AC charging terminal. This AC port is optional. In another embodiment, however just the AC charging port can be there and the DC charging is either optional or not there. In figure 2.10 and 2.12, the high voltage DC input port (116) shown here as a straight connector, in another embodiment a different connector compatible with a particular manufacturer's cable can be used with harnesses. In figure 2.10 and 2.12 the AC input port (116) shown is a single phase wall socket, in another embodiment it can be a three phase AC connector, compatible with a particular manufacturer's cable with harnesses.

In figure 2.12 and figure 3, in this particular embodiment the BPBT(100) is shown with low voltage DC output port (118) with positive and negative terminals electrically connected to an electric vehicle's low voltage/auxiliary battery 's (34) positive and negative terminals e.g. a lead acid battery. In another embodiment there could be an additional low voltage DC output port which allows electrical connector to a second battery e.g. first connection connects to a 12V battery and the second connector connects to a 48V battery. The electrical connection shown port (118) and the low battery shown here is a 2 way connection, which means low voltage battery also supplies power to the BPBT (used to power the relays). In another embodiment it could be just one way e.g. the BPBT can charge the battery, however the low voltage battery (34) does not supply charge to the BPBT(100). In further embodiment it could be one battery (34) connection is one way, however the second low voltage battery (34) is two way e.g. 12V battery connection is one way and 48V battery connection is two way.

In figure 2.12 and figure 3, in this particular embodiment, the BPBT is shown with communication port (117), which is a serial port, electronically connected to vehicle control unit (41) of an electric vehicle. In another embodiment there could be one or more additional ports e.g. an Ethernet port, a CAN port. In further embodiment the additional port can be electronically connected to a another vehicle control unit, e.g. a vehicle may have two or more vehicle/motor control units to control front and rear wheels motors (31) connected to two separate ports at the BPBT.

In figure 2.12 and figure 3, in this particular embodiment, the communication port (117) is electronically connected to a GUI (graphical user interface) (42) within the vehicle. In another embodiment the port (117) can be connected to a navigation and autonomous driving system. In further embodiment the port (117) can be connected to user's own screen mounted device e.g. off the shelf navigation devices.

In figure 3, in this particular embodiment, the BPBT(100) is a single large battery device installed in an electric vehicle. In another embodiment there can be more than one BPBT (100) installed in an electric vehicle electrically connected in a serial or parallel manner e.g. to provide more capacity or voltage to a larger vehicle e.g. there can be two BPBT(100) installed in a train carriage with two wheelsets, one BPBT (100) for each wheelset.

In figure 2.12 and figure 3, in this particular embodiment, the BPBT(100) is a single large battery device installed in an electric vehicle and the communication port (117) of this BPBT electronically connects to a vehicle control unit which can provide instructions to the BPBT regarding its operations. In another embodiment two or more BPBT are installed in an electric vehicle e.g. in a train carriage. These BPBT (100) can be independently controlled by the vehicle control unit or all the BPBT can be electronically chained, such that an vehicle control unit can manage all the BPBT by electronically connecting to just one of the BPBT and the connected BPBT's battery pack controller (140) acts as the master of other BPBT(100) and the latter's battery pack controllers (140) act as a slave.

In figure 2.11 and figure 3, in this particular embodiment, the thermal port (114) is thermally connected to an external pump (23), which pumps cold water/refrigerant through the inlet of port (114) and extracts hot water/ refrigerant through the outlet of port (114). In figure 2.11 and figure 3, the low voltage DC port (111) supplies power to the pump and communication port (119) is electronically connected to the pump's control unit. In another embodiment the thermal port (114) is thermally connected to vehicle's heat exchanger which directly pumps in cold water/refrigerant through the inlet of port (114) and extracts hot water/ refrigerant through the outlet of port (114); and port (119) is electronically connected to vehicle control unit to instruct how much water/refrigerant supply it needs and when.

In figure 2.12 and figure 3, in this particular embodiment, the communication port (117) is electronically connected to internet using wifi (43) or Bluetooth (43). In another embodiment the communication port (117) is connected to user's smartphone app to provide information about the status of the battery pack and receive instructions from the user. In further embodiment the port (117) is connected to the internet based app which remotely monitors the health of the BPBT and provides instructions e.g. to start charging and stop charging. In another embodiment the port (117) is connected to the cloud based operational centre to:

a. provide detailed information on request for remote monitoring e.g. contextual data, sensor data, warning notifications etc;
b. and receive information and instructions which are specific to the battery pack e.g. SoH, Failure of the BMs, prediction of failure, need service etc.

Example of intended use

- Power unit for large electric vehicles e.g. trucks, SUVs, vans, trains
- Backup power unit for hospitals, data centres and industrial units
- Energy storage unit for solar panels

Claims

A Method of protecting a battery pack from thermal stresses

1. A method of protecting a battery pack from thermal stresses, comprising:
    a. packing a plurality of rechargeable batteries inside plurality of modules, and packing the plurality of said modules inside a closed container;
    b. stacking the said modules horizontally and/or vertically inside the said container;
    c. fully immersing the plurality of said rechargeable batteries and the said modules, in a 2 phase (liquid and vapour) dielectric liquid, inside the said container;
    d. thermally connecting the container to atleast one condenser, either a condenser which is fitted inside the said container, or a condenser which is fitted outside the container;
    e. collecting the subcooled condensate and delivering the subcooled condensate at the base of the container, either inside the container, or by siphoning off the vapours and condensing the vapours in a heat exchanger and returning the subcooled condensate at the base of the container;
    f. creating vertical ducts through the modules, by aligning the openings in the top and bottom plates of the said modules;
    g. the bubbles creating a vertical two-phase flow of said dielectric liquid and bubbles inside the said ducts;
    h. the said ducts working as a heat exchangers; subcooled dielectric liquid entering the ducts at the bottom of the stacked modules and hot liquid leaving the ducts at the top of the stacked modules, the process known as 'subcooled flow boiling' transferring the heat from the batteries to the dielectric liquid, helping to create an efficient heat transport process to transport heat from the vertically stacked said modules;
    i. creating a circular flow of subcooled liquid inside the container, and this subcooled liquid cooling the batteries/electronics as it rises through the stacked batteries, and the vapours thus produced after cooling the batteries/electronics being condensed by the condenser, the subcooled condensate returning directly to the base of the container; and continuing the circular flow of the subcooled liquid.
2. The method of claim 1 also involves thermally connecting the said container to a heater, it can be an electric heater fitted inside the said container; or a set of heating pipes fitted inside the container which are heated by piped in hot water/refrigerant.
3. The method of claim 1 also involves the said vertical flow of dielectric liquid creating a low pressure inside the said ducts, and the low pressure creating a localised horizontal flow of liquid towards the ducts; and the low pressure sucking in hot liquid from the gaps in between the stacked modules, which in turn sucking in hot liquid from the tabs of the batteries; harnessing the effects documented in Bernoulli's theorem.
4. The method of claim 1 also involves actively cooling the condenser using a pump to push cold water or water + ethanol through the condenser.
5. The method of claim 1 cooling step also involves bubbles producing a vertical flow of said dielectric liquid through the said ducts, which pushes the hot/boiling dielectric liquid towards the surface of the liquid within the container.

6. The method of claim 1 cooling step also involves cooling of the electronics which is installed inside the container; preferably including:
    a. Power board to charge large number of rechargeable batteries;
    b. Battery pack controller board;
    c. Relay switches.
7. The method of claim 1 the cooling step also involves either during extremely high ambient temperatures or during the heavy use of the batteries:
    a. allowing the already hot dielectric liquid to evaporate on the surface of the said batteries;
    b. capturing the further heat produced by the batteries using the latent heat of the dielectric liquid;
    c. increasing the flow of cooling liquid through the condenser;
    d. continuing to remove the heat from the condenser as fast as possible until the temperature of the dielectric liquid falls below the boiling point;
    e. and avoiding the build up of vapours in the said container, which slows the vertical flow of the vapours and the dielectric liquid through the said ducts.
8. The method of claim 2 the heating step also involves heating the cold batteries, by transferring the heat from the said heater, to the said dielectric liquid, and then transferring the heat from the said dielectric liquid to the batteries, with cold batteries also acting as a condenser.
9. The method of claim 2 the heating step also involves switching on the heaters by the battery pack controller.
10. The method of claim 2 the heating step also involves battery pack controller deciding the need to switch on the heater based on the temperature readings of batteries below the minimum operating temperature of the batteries.
11. The method of claim 2 the heating step also involves phase change of said dielectric liquid to bubbles when cold liquid in the sumps of the container coming in contact with the hot heater, as well as heating the dielectric liquid by convection.
12. The method of claim 2 the heating step also involves the bubbles creating a vertical flow of heated dielectric liquid through the ducts.
13. The method of claim 2 the heating step also involves the said ducts acting as heat exchangers with heated liquid entering the bottommost module and cooler liquid leaving the topmost module, and dielectric liquid transferring the heat to the said batteries.
14. The method of claim 2 the heating step also involves during extremely low ambient temperatures:
    a. the said heater is preferably heated by the charge stored in the capacitors;
    b. the hot heater heating the cold dielectric liquid, preferably not frozen, in the sump by convection and producing bubbles;
    c. continuing heating the dielectric liquid, until the temperature of the dielectric liquid in the container coming close to the minimum operating temperature of the batteries;
    d. and avoiding heating the dielectric liquid too fast which converts the dielectric liquid in the sump, into such an amount of vapour which when travels through the said ducts, may reduce contact of the heated dielectric liquid to the cold batteries.

15. The method of claim 1 also involves immersion proof breather balancing the pressure inside the container and the external pressure; however where the BPBT is used in high altitudes applications omitting the immersion proof breather as vapours are used to increasing the pressure inside the container and hence increasing the boiling point of the dielectric liquid.
16. The method of claim 1 also involves protecting the container from extreme ambient temperatures using thermal insulation.
17. The method of claim 1 the cooling steps also involve battery pack controller activating the gas solenoid valve when, either the pressure inside the container increases beyond the preset pressure, or for removing any gases and smoke from a fire or thermal runaway.
18. The method of claim 1 the cooling steps also involve using a shape of the lid of the container which channels the vapours to the condenser; preferably using a parabolic lid.
19. The method of claim 1 also involves collecting the condensate inside the container using one or more troughs.
20. The method of claim 1 the cooling steps also involve avoiding the build of pressure inside the container using a gas solenoid.

A method of providing flood protection to a battery pack

21. The method of claim 1 also involves the sealed container providing flood protection to the batteries and the electronics, comprising:
    a. extinguishing any incidence of fire inside the said container using the fire extinguishing properties of the dielectric liquid;
    b. removing any gas and smoke from a fire, from the said container using gas solenoid;
    c. releasing the build up of pressure inside the container using immersion proof breather/s.

A method of cooling the battery pack in extreme hot temperatures

22. The method of claim 1 also involves cooling the battery pack in extreme temperatures, comprising Battery pack controller controlling the battery pack/modules output such that it supplies charge from the capacitors to the external pump/s of the condenser/s when the temperature inside the container increases beyond a preset level.

A method of heating the battery pack in extreme cold temperatures

23. The method of claim 1 also involves heating the battery pack in extreme cold temperatures, comprising Battery pack controller controlling the battery pack/modules output such that it supplies current from capacitors to the heater/s when the temperature inside the container falls below the preset level.

24. The method of claim 1 also involves communicating with vehicle control unit to instruct how much water/refrigerant supply the condenser/s needs and when.

25. The method of claim 1 also involves thermally connecting the thermal ports of the container to an external pump, either a pump which pumps cold water/refrigerant through the inlet port and extracts hot water/ refrigerant through the outlet port, or vehicle's heat exchanger's pump which pumps in cold water/refrigerant through the inlet port and extracts hot water/ refrigerant through the outlet port.

Glossary

Dielectric liquid – is a dielectric material (thermally conductive but electrically insulative) in a liquid state. E.g. flurocarbons

Multi layer faced/sided PCB – printed circuit board with multi layers

auxiliary batteries - low voltage batteries

Smartphone – personally held devices like phone or tablets e.g. iPhone or Samsung

Vehicle control system – control system of the vehicle