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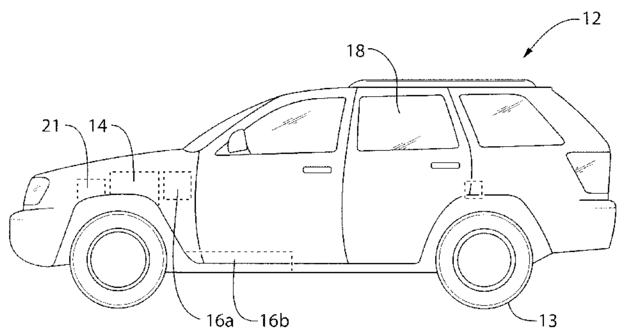

FIG. 1

(57) **Abstract**: A vehicle, such as a parallel or series hybrid vehicle, includes both an electric traction motor and a range extending device such as, for example, an internal combustion engine, or a fuel cell. In an embodiment, a thermal management system for the vehicle includes a passenger cabin heating circuit configured to circulate heat exchange fluid through a liquid-to-liquid heat exchanger and a passenger cabin heating heat exchanger. A motor circuit can be configured to circulate heat exchange fluid through the electric traction motor, a transmission control module, and a DC/DC converter. The motor circuit can be selectably connected to the passenger cabin heating circuit by a valve. An engine circuit is configured to circulate heat exchange fluid through the internal combustion engine, a radiator, and the liquid-to-liquid heat exchanger. The liquid-to-liquid heat exchanger is configured to transfer heat between heat exchange fluid of the passenger cabin heating circuit and heat exchange fluid of the engine circuit.

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THERMAL MANAGEMENT SYSTEM AND RELATED METHODS FOR VEHICLE HAVING ELECTRIC TRACTION MOTOR AND RANGE EXTENDING DEVICE

FIELD OF THE INVENTION

[0001] The present disclosure relates to vehicles, and, more particularly to vehicles that include both an electric traction motor and a range extending device such as, for example, an internal combustion engine, or a fuel cell.

BACKGROUND OF THE INVENTION

[0002] Vehicles with electric traction motors offer the promise of powered transportation while producing little or no emissions at the vehicle. Some vehicles are powered by electric motors only and rely solely on the energy stored in an on-board battery pack. Some vehicles are hybrids, having both a traction motor and an internal combustion engine, which may, for example, be used to assist the traction motor in driving the wheels (a parallel hybrid), or which may, for example, be used solely to charge the on-board battery pack, thereby extending the operating range of the vehicle (a series hybrid). In some vehicles, there is a single, centrally-positioned electric motor that powers one or more of the vehicle wheels, and in other vehicles, one or more of the wheels have an electric motor (referred to sometimes as a hub motor) positioned at each driven wheel.

[0003] While currently proposed and existing hybrid vehicles are advantageous in some respects over vehicles powered solely by internal combustion engines, there are problems that are associated with some hybrid vehicles. It would be beneficial to provide technology that improves the efficiency with which power is used in the operation of these vehicles.

SUMMARY OF THE INVENTION

[0004] In an aspect, the invention is directed to a vehicle includes an electric traction motor and a range extending device such as, for example, an internal combustion engine, or a fuel cell. Heat generated by each of the electric traction motor and the range extending device can be used to heat a passenger cabin of the vehicle. A radiator can be used to cool the electric traction motor and the range extending device. Heat generated by the electric traction motor or by other electrical components of the vehicle can be used to heat battery packs of the vehicle.

[0005] In a second aspect, the invention is directed to a thermal management system for a vehicle wherein the system includes a first fluid circuit used to control the temperature of one or more components of the vehicle such as, for example, the passenger cabin, components related to a battery pack of the vehicle, power electronics components, an electric traction motor, or the like. It will be understood that in any given embodiment the vehicle need not have all these items be controlled by the first fluid circuit. The system further includes a second fluid circuit and a range extending device such as, for example, an internal combustion engine or a fuel cell, that, when operating, heats fluid in the second fluid circuit. A liquid-to-liquid heat exchanger is provided to transfer heat between the first and second fluid circuits.

[0006] In an embodiment of the second aspect, a thermal management system for a vehicle is provided including a passenger cabin heating circuit configured to circulate heat exchange fluid through a liquid-to-liquid heat exchanger and a passenger cabin heating heat exchanger, and a second circuit configured to circulate heat exchange fluid through a range extending device (such as, for example, an internal combustion engine, or a fuel cell), a radiator, and the liquid-to-liquid heat exchanger. The liquid-to-liquid heat exchanger is configured to transfer heat between heat exchange fluid of the passenger cabin heating circuit and heat exchange fluid of the second circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The present disclosure will now be described, by way of example only, with reference to the attached drawings, in which:

[0008] Figure 1 is a perspective view of a vehicle that includes a thermal management system in accordance with an embodiment of the present disclosure;

[0009] Figure 2 is a schematic illustration of a thermal management system for the vehicle of Figure 1;

[0010] Figure 3 is a block diagram of a controller for the thermal management system of Figure 2;

[0011] Figure 4 is a schematic illustration of another embodiment of a thermal management system for the vehicle of Figure 1;

[0012] Figure 5 is a graph of the temperature of battery packs that are part of the vehicle shown in Figure 1; and

[0013] Figures 6a-h show schematic diagrams of heating and cooling configurations of the thermal management system.

DETAILED DESCRIPTION OF THE INVENTION

[0014] Reference is made to Figure 1, which shows a vehicle 12. The vehicle 12 includes wheels 13, an electric traction motor 14 for driving the wheels 13, first and second battery packs 16a and 16b, a passenger cabin 18, a high voltage electrical system 20 (Figure 2), a low voltage electrical system, and a range extending device 21 that in this example is an internal combustion engine 21.

[0015] The motor 14 may have any suitable configuration for use in powering the vehicle 12. The motor 14 may be mounted in a motor compartment that is forward of the cabin 18. The motor 14 may be connected to a gearbox (not shown) which drives the wheels 13. The motor 14 is an electrical component that generates heat during use and thus requires cooling. To this end, the motor 14 includes a motor fluid flow conduit for transporting heat exchange fluid (e.g., coolant) about the motor 14, so as to maintain the motor 14 within a suitable temperature range.

[0016] The internal combustion engine 21 may also have any suitable configuration for use in the vehicle 12. For example, the internal combustion engine 21 may, for example, be a gasoline engine or it may be a diesel engine. Alternatively other fuels may be used, such as LNG. The engine 21 could be a reciprocating-type engine, or, for example, it may be a Wankel (rotary) type engine. The internal combustion engine 21 may be connected to one or more generators or alternators to generate electrical power to charge the battery packs 16a and 16b. The internal combustion engine 21 may be known as a range extender. Alternatively, the internal combustion engine 21 may be connected to a drivetrain for directly powering the wheels 13. The configuration of the internal combustion engine 21 with respect to the electric traction motor 14 may designate the vehicle 12 as a series or parallel hybrid vehicle. The internal combustion engine 21 may be located in the motor compartment with the motor 14 or at a different location. The internal combustion engine 21 generates heat during use and thus requires cooling. To this end, the internal combustion engine 21 includes an engine fluid flow conduit for transporting heat exchange fluid about the internal combustion engine 21, so as to maintain the internal combustion engine 21 within a suitable temperature range.

[0017] Reference is made to Figure 2, which shows a schematic illustration of a thermal management system 10 for the vehicle 12. Components forming part of and served by the thermal management system 10 are shown, while other components of the vehicle 12 are omitted for the sake of clarity.

[0018] A transmission control module shown at 28 is part of the high voltage electrical system 20 and is provided for controlling the current flow to high voltage electrical loads within the vehicle 12, such as the motor 14, an air conditioning compressor 30, a heater 32 and a DC/DC converter 34. The transmission control module 28 is an electrical component that generates heat during use and thus has a transmission control module fluid flow conduit associated therewith for transporting heat exchange fluid about the transmission control module 28, so as to maintain the transmission control module 28 within a suitable temperature range. The transmission control module 28 may be positioned immediately upstream fluidically from the motor 14.

[0019] The DC/DC converter 34 receives current from the transmission control module 28 and converts it from high voltage to low voltage. The DC/DC converter 34 sends the low voltage current to a low voltage battery (not shown), which is used to power low voltage loads in the vehicle 12. The low voltage battery may operate at any suitable voltage, such as 12 V. The DC/DC converter 34 is an electrical component that generates heat during use and thus has a DC/DC converter fluid flow conduit associated therewith for transporting heat exchange fluid about the DC/DC converter 34, so as to maintain the DC/DC converter 34 within a suitable temperature range.

[0020] The battery packs 16a and 16b send power to the transmission control module 28 for use by the motor 14 and other high voltage loads and thus form part of the high voltage electrical system 20. The battery packs 16a and 16b may be any suitable types of battery packs. In an embodiment, the battery packs 16a and 16b are each made up of a plurality of lithium polymer cells. The battery packs 16a and 16b have a temperature range (shown in Figure 5) in which they are preferably maintained so as to provide them with a relatively long operating life. While two battery packs 16a and 16b are shown, it is alternatively possible to have any suitable number of battery packs, such as one battery pack, or three or more battery packs depending on the packaging constraints of the vehicle 12.

[0021] A battery charge control module shown at 42 is provided and is configured to connect the vehicle 12 to an external electrical source (e.g., a 110 V source or a 220 V source) shown at 44, and to send the current received from the electrical source 44 to any of several destinations, such as, the battery packs 16a and 16b, the transmission control module 28 and the low voltage battery. The battery charge control module 42 generates heat during use and thus requires cooling. To this end, the battery charge control module 42 includes a battery charge control module fluid flow conduit for transporting fluid about the battery charge control module 42 so as to maintain the battery charge control module 42 within a suitable temperature range.

[0022] A heating, ventilation, and air conditioning (HVAC) system 46 is provided for controlling the temperature of the passenger cabin 18 (Figure 1). The HVAC system 46 is configured to be capable of both cooling and heating the cabin 18. To achieve this, the HVAC system 46 may include one or more heat exchangers, such as a passenger cabin heating heat exchanger 47 and a passenger cabin cooling heat exchanger 48 (which may be referred to as evaporator 48). The cabin heating heat exchanger 47 has a heat exchange fluid inlet 49 and a heat exchange fluid outlet 50 and is used to heat an air flow that is passed into the cabin 18. The cabin cooling heat exchanger 48 includes a refrigerant inlet 51 and a refrigerant outlet 52, and is used to cool an air flow that is passed into the cabin 18.

[0023] The motor 14, the engine 21, the transmission control module 28, the DC/DC converter 34, the battery packs 16a and 16b, the battery charge control module 42, and the HVAC system 46 constitute thermal loads on the thermal management system 10.

[0024] The thermal management system 10 includes a motor circuit 56, a second or engine circuit 57, a cabin heating circuit 58, a battery circuit 60 and a main cooling circuit 62.

[0025] The motor circuit 56 is configured for cooling the traction motor 14, the transmission control module 28, and the DC/DC converter 34, which constitute a motor circuit thermal load 61. The motor circuit thermal load 61 has a motor circuit thermal load inlet 63 and a motor circuit thermal load outlet 65. The motor circuit 56 includes a first motor circuit conduit 66 fluidically between a cabin heating circuit valve 88 and the motor circuit thermal load inlet 63, a second motor circuit conduit 68 fluidically between the motor circuit thermal load outlet 65 and the cabin heating circuit valve 88, and a motor circuit pump 70 positioned to pump heat exchange fluid through the motor circuit 56.

[0026] The motor circuit pump 70 may be positioned anywhere suitable, such as in the first motor circuit conduit 66. The motor circuit pump 70 may be a variable-speed electric pump.

[0027] The elements that make up the motor circuit thermal load 61 may be arranged in any suitable way. For example, the DC/DC converter 34 may be downstream from the pump 70 and upstream from the transmission control module 28, and the motor 14 may be downstream from the transmission control module 28. Thus, the inlet to the DC/DC converter 34 constitutes the thermal load inlet 63 and the motor outlet constitutes the thermal load outlet 65.

[0028] A motor circuit temperature sensor 76 is provided for determining the temperature of heat exchange fluid at a selected point in the motor circuit 56. As an example, the motor circuit temperature sensor 76 may be positioned downstream from the motor circuit thermal load 61, so as to sense the highest temperature of the heat exchange fluid.

[0029] The engine circuit 57 is configured for cooling the internal combustion engine 21, which constitutes an engine circuit thermal load 67 that has an engine circuit thermal load inlet 69 and an engine circuit thermal load outlet 71. The engine circuit 57 includes a first engine circuit conduit 73 fluidically between a heat exchanger 99 and the engine circuit thermal load inlet 69, a second engine circuit conduit 77 fluidically between the engine circuit thermal load outlet 71 and a radiator 64, a third engine circuit conduit 81 fluidically between the radiator 64 and the heat exchanger 99, and a second or engine circuit pump 79 positioned to pump heat exchange fluid through the engine circuit 57.

[0030] The engine circuit pump 79 may be positioned anywhere suitable, such as in the second engine circuit conduit 77. The engine circuit pump 79 may be a variable-speed electric pump.

[0031] Additional elements may be included in the engine circuit thermal load 67, and these may be arranged relative to the engine 21 in any suitable configuration.

[0032] Additionally, a fourth engine circuit conduit 74 may be provided fluidically between the second and third engine circuit conduits 77 and 81, so as to permit the flow of heat exchange fluid to bypass the radiator 64. To control whether the flow of heat exchange fluid is directed through the radiator 64 or through the fourth engine circuit conduit 74, a radiator bypass valve 75 is provided and may be positioned in the second engine circuit conduit 77. The radiator bypass valve 75 is controllable so that in a first position it directs the flow of heat exchange fluid to the radiator 64 through the second engine circuit conduit 77 and in a second position it directs the flow of heat exchange fluid to the third engine circuit conduit 81 through the fourth engine circuit conduit 74, so as to bypass the radiator 64. By permitting the temperature of the heat exchange fluid to rise, the engine can more easily reach an operating temperature at which its emissions are relatively low and its combustion efficiency is relatively high. Furthermore, flow through the fourth engine circuit conduit 74 may in some embodiments be easier than flow through the radiator 64 (i.e., there is less of a pressure drop associated with flow through the fourth conduit 74 than there is with flow through the radiator 64), and so bypassing the radiator 64 whenever possible reduces the energy consumption of the pump 79 and of the thermal management system 10. Furthermore, bypassing the radiator 64 may permit the fan (shown at 144) to be kept off, which further reduces the energy consumption of the thermal management system 10.

[0033] When the radiator bypass valve 75 is in its first position, all of the heat exchange fluid flow is directed through the second conduit 77, through the radiator 64, and through the third conduit 81. Conversely, when the radiator bypass valve 75 is in its second position, all of the heat exchange fluid flow is directed through the fourth conduit 74 and into the third conduit 81 towards the heat exchanger 99. There can be no backflow from the fourth conduit 74 into the radiator 64 because of the fluid already present between the radiator 64 and the fourth conduit 74. Thus, using only a single valve (i.e., the bypass valve 75) provides the capability of selectably bypassing the radiator 64, instead of using one valve at the junction of the second and fourth conduits 77 and 74 and another valve at the junction of the third and fourth conduits 81 and 74. As a result of using one valve (i.e., valve 75) instead of two valves, the engine circuit 57 contains fewer components, thereby making it less expensive, simpler to make and operate, and more reliable. Furthermore, by eliminating one valve, the energy required to move the heat exchange fluid through the engine circuit 57 is reduced, thereby reducing the energy consumed by the pump 79 and extending the range of the vehicle 12.

[0034] An engine circuit temperature sensor 83 is provided for determining the temperature of heat exchange fluid at a selected point in the engine circuit 57. As an example, the engine circuit temperature sensor 83 may be positioned downstream from the engine circuit thermal load 67 to provide an indication of the temperature of the engine 21. Based on this temperature, a controller 78 (Figure 3) can determine whether or not to position the radiator bypass valve 75 in its first position or second position.

[0035] The cabin heating circuit 58 is configured for providing heated heat exchange fluid to the HVAC system 46 and more specifically to the cabin heating heat exchanger 47, which constitutes the cabin heating circuit thermal load. The cabin heating circuit 58 includes a first cabin heating circuit conduit 80 fluidically between the second motor circuit conduit 68 and the cabin heating heat exchanger inlet 49 (which in the embodiment shown is the inlet to the cabin heating circuit thermal load), and a second cabin heating circuit conduit 82 fluidically between the cabin heating circuit heat exchanger outlet 50 (which in the embodiment shown is the outlet from the cabin heating circuit thermal load) and the first motor circuit conduit 66. In the embodiment shown, the second cabin heating circuit conduit 82 extends to the valve 88 at the first motor circuit conduit 66.

[0036] In some situations the heat exchange fluid will not be sufficiently hot to meet the demands of the HVAC system 46. For such situations, the heater 32 which may be referred to as the cabin heating circuit heater 32 is provided in the first cabin heating circuit conduit 80. The cabin heating circuit heater 32 may be any suitable type of heater, such as an electric heater that is one of the high voltage electrical components fed by the transmission control module 28.

[0037] A third cabin heating circuit conduit 84 may be provided between the second and first cabin heating circuit conduits 82 and 80. A cabin heating circuit pump 86 is provided in the third conduit 84. In some situations it will be desirable to circulate heat exchange fluid through the cabin heating circuit 58. For example, when the fluid is being heated by the heater 32, it may be advantageous to not transfer the fluid to the motor circuit 56 since the fluid in the motor circuit 56 is used for cooling the motor circuit thermal load 61, and it thus may be undesirable to introduce hot fluid into the motor circuit 56. For the purpose of preventing heat exchange fluid from being transferred between the cabin heating circuit 58 and the motor circuit 56, the cabin heating circuit valve 88 is provided. In the embodiment shown, the cabin heating circuit valve 88 is positioned in the second motor circuit conduit 68 and is selectably positionable in a first position wherein the valve 88 directs fluid flow towards the first motor circuit conduit 66 through the second motor circuit conduit 68, and a second position wherein the valve 88 directs fluid flow towards the cabin heater heat exchanger 47 through the first cabin heating circuit conduit 80.

[0038] When the cabin heating circuit valve 88 is in the second position, the pump 86 may operate at a selected low flow rate to prevent the fluid flow from short circuiting the cabin heating circuit by flowing back through the third conduit 84 towards the second conduit 82.

[0039] It will be noted that separation of the fluid flow through the cabin heating circuit 58 and the motor circuit 56 is achieved using a single valve (i.e., valve 88), which is positioned at the junction of the second motor circuit conduit 68 and the first cabin heating circuit conduit 80. When the valve 88 is positioned in the first position, fluid is directed back into the motor circuit 56 via the first motor circuit conduit 66. There is no net flow out of the cabin heating circuit 58 since there is no flow into the cabin heating circuit 58. When the valve 88 is positioned in the second position and the pump 86 is off, fluid is directed through the cabin heating circuit 58 and back into the motor circuit 56. When the valve 88 is positioned in the first position and the pump 86 is on, there is no net flow out of the second cabin heating circuit conduit 82 as noted above, however, the pump 86 generates a fluid circuit loop and drives fluid in a downstream portion 90 of the first cabin heating circuit conduit 80, through the cabin heating heat exchanger 47, and through an upstream portion 92 of the second cabin heating circuit conduit 82, whereupon the fluid is drawn back into the pump 86. Because this feature is provided using a single valve (i.e., valve 88), as opposed to using one valve at the junction of the first cabin heating circuit conduit 80 and the motor circuit 56 and another valve at the junction of the second cabin heating circuit conduit 82 and the motor circuit 56, the thermal management system 10 is made simpler and less expensive, and it further saves energy consumption by having fewer valves in the system 10 so as to reduce the energy required by the pump 70 to pump liquid through such valves.

[0040] Additionally, the valve 88 combined with the pump 86 permits isolating heat exchange fluid in the cabin heating circuit 58 from heat exchange fluid in the motor circuit 56, thereby preventing fluid that has been heated in the cabin heating circuit heater 32 from being sent to the motor circuit 56.

[0041] A cabin heating circuit temperature sensor 94 may be provided for determining the temperature of the fluid in the cabin heating circuit 58. The temperature sensor 94 may be positioned anywhere suitable, such as downstream from the heat exchanger 99. The temperature sensor 94 may communicate with the controller 78 so that the controller 78 can determine whether or not to carry out certain actions. For example, using the temperature sensed by the temperature sensor 94, the controller 78 can determine whether the heater 32 should be activated to meet the cabin heating demands of the HVAC system 46 as requested by a climate control system.

[0042] The heat exchanger 99 is part of both the cabin heating circuit 58 and the engine circuit 57. Regarding the cabin heating circuit 58, the heat exchanger 99 is located in the first cabin heating circuit conduit 80, upstream of the heater 32. Regarding the engine circuit 57, the heat exchanger 99 is located between the third engine circuit conduit 81 and the first engine circuit conduit 73, downstream of the radiator 64. The heat exchanger 99 can be liquid-to-liquid heat exchanger that allows heat transfer between the heat exchange fluid in the cabin heating circuit 58 and the heat exchange fluid in the engine circuit 57, while preventing communication (i.e., mixing) of heat exchange fluid between the cabin heating circuit 58 and the engine circuit 57.

[0043] The battery circuit 60 is configured for controlling the temperature of the battery packs 16a and 16b and the battery charge control module 42, which together make up the battery circuit thermal load 96. A thermal load inlet is shown at 98 upstream from the battery packs 16a and 16b and a thermal load outlet is shown at 100 downstream from the battery charge control module 42. The battery packs 16a and 16b are in parallel in the battery circuit 60, which permits the fluid flow to each of the battery packs 16a and 16b to be selected individually so that each battery pack 16a or 16b receives as much fluid as necessary to achieve a selected temperature change. A valve for adjusting the flow of fluid that goes to each battery pack 16a and 16b during use of the thermal management system 10 may be provided, so that the fluid flow can be adjusted to meet the instantaneous demands of the battery packs 16a and 16b. After the fluid has passed through the battery packs 16a and 16b, the fluid is brought into a single conduit which passes through the battery charge control module 42. While the battery packs 16a and 16b are shown in parallel in the battery circuit 60, they could be provided in series in an alternative embodiment.

[0044] A first battery circuit conduit 102 extends between the second motor circuit conduit 68 and the battery circuit thermal load inlet 98. A second battery circuit conduit 104 extends between the thermal load outlet 100 and the first motor circuit conduit 66. A battery circuit pump 106 may be provided for pumping fluid through the battery circuit 60 in situations where the battery circuit 60 is isolated from the motor circuit 56. A battery circuit heater 108 is provided in the first conduit 102 for heating fluid upstream from the battery circuit thermal load 96 in situations where the battery circuit thermal load 96 requires it. The battery circuit heater 108 may operate on current from a low voltage current source, such as the low voltage battery.

[0045] A third battery circuit conduit 110 may be provided fluidically between the second and first battery circuit conduits 102 and 104 so as to permit the flow of heat exchange fluid in the battery circuit 60 to be isolated from the flow of heat exchange fluid in the motor circuit 56. A chiller 112 may be provided in the third conduit 110 for cooling fluid upstream from the thermal load 96 when needed.

[0046] A battery circuit valve 114 is provided in the second conduit 104 and is positionable in a first position wherein the flow of fluid is directed towards the first motor circuit conduit 66 and in a second position wherein the flow of fluid is directed into the third battery circuit conduit 110 towards the first battery circuit conduit 102.

[0047] It will be noted that the flow in the battery circuit 60 is isolated from the flow in the motor circuit 56 by only one valve (i.e., valve 114). When the valve 114 is in the second position, so as to direct fluid flow through the third conduit 110 into the first conduit 102, there is effectively no flow from the first motor circuit 56 through the first conduit 102 since the loop made up of the downstream portion of the first conduit 102, the thermal load 96, the second conduit 104, and the third conduit 110 is already full of fluid. By using only one valve (i.e., valve 114) to isolate the battery circuit 60, the amount of energy consumed by the pump 106 to pump fluid around the battery circuit 60 is reduced relative to a similar arrangement using two valves. Additionally, by using only one valve the battery circuit is simpler (i.e., it has fewer components), which reduces its cost and which could increase its reliability.

[0048] A battery circuit temperature sensor 116 is provided for sensing the temperature of the fluid in the battery circuit 60. The temperature sensor 116 may be positioned anywhere in the battery circuit 60, such as in the second conduit 104 downstream from the thermal load 96. The temperature from the temperature sensor 116 can be sent to the controller 78 to determine whether the valve 114 should be in the first or second position and whether any devices (e.g., the chiller 112, the heater 108) need to be operated to adjust the temperature of the fluid in the first conduit 102.

[0049] The main cooling circuit 62 is provided for assisting in the thermal management of the thermal loads in the HVAC system 46 and the battery circuit 60. More particularly, the thermal load in the HVAC system 46 is shown at 118 and is made up of the cabin cooling heat exchanger 48 (i.e., the evaporator 48).

[0050] The components of the main cooling circuit 62 that are involved in the cooling and management of the refrigerant flowing therein include the compressor 30 and a condenser 122. A first cooling circuit conduit 126 extends from the condenser 122 to a point where the conduit 126 divides into a first branch 128 which leads to the HVAC system 46 and a second branch 130 which leads to the battery circuit 60. A second cooling circuit conduit 132 has a first branch 134 that extends from the HVAC system 46 to a joining point and a second branch 136 that extends from the battery circuit 60 to the joining point. From the joining point, the second cooling circuit conduit 132 extends to the inlet to the compressor 30.

[0051] At the first branch 128 of the first conduit 126 is a flow control valve 138 which controls the flow of refrigerant into the cabin cooling heat exchanger 48. The first branch 134 of the second conduit 132 is connected to the refrigerant outlet from the heat exchanger 48. It will be understood that the valve 138 could be positioned at the first branch 134 of the second conduit 132 instead. The valve 138 is controlled by the controller 78 and is opened when refrigerant flow is needed through the evaporator 48.

[0052] At the second branch 130 of the first conduit 126 is a flow control valve 140 which controls the flow of refrigerant into the battery circuit chiller 112. The second branch 136 of the second conduit 132 is connected to the refrigerant outlet from the chiller 112. It will be understood that the valve 140 could be positioned at the second branch 136 of the second conduit 132 instead. The valve 140 is controlled by the controller 78 and is opened when refrigerant flow is needed through the chiller 112.

[0053] The valves 138 and 140 may be any suitable type of valves with any suitable type of actuator. For example, they may be solenoid actuated/spring return valves. Additionally, thermostatic expansion valves shown at 139 and 141 may be provided downstream from the valves 138 and 140.

[0054] A refrigerant pressure sensors 142 and 143 may be provided anywhere suitable in the cooling circuit 62, such as between the compressor 30 and the condenser 122 and upstream of the compressor 30 in the second conduit 132. The pressure sensors 142 and 143 communicate pressure information from the cooling circuit 62 to the controller 78 to assist in controlling the cooling circuit 62.

[0055] A fan shown at 144 is provided for blowing air on the radiator 64 and the condenser 122 to assist in cooling and condensing the heat exchange fluid and the refrigerant respectively. The fan 144 is a variable-speed fan that is controlled by the controller 78.

[0056] Expansion tanks 124a and 124b are provided for removing gas that can accumulate in components of the motor circuit 56 and engine circuit 57. The expansion tank 124a serves the motor circuit 56, and has an inlet connected to the transmission control module 28 and the second battery circuit conduit 104 and an outlet connected to the first motor circuit conduit 66. The expansion tank 124b serves the engine circuit 57, and has an inlet connected to the radiator 64 and an outlet connected to the first engine circuit conduit 73. The expansion tank 124a is positioned at or above the highest elevation of any fluid-carrying component of the motor circuit 56 and battery circuit 60. The expansion tank 124b is positioned at or above the highest elevation of any fluid-carrying component of the engine circuit 57. The expansion tank 124a may be used as point of entry for heat exchange fluid into the motor circuit 56 and the battery circuit 60. The expansion tank 124b may be used as point of entry for heat exchange fluid into the engine circuit 57. In this embodiment, separate expansion tanks 124a and 124b are used, instead of a single common tank, because the motor and battery circuits 56 and 60 are fluidically isolated from the engine circuit 57. Accordingly, the expansion tanks 124a and 124b may contain different types or different concentrations of heat exchange fluid.

[0057] Figure 3 illustrates the controller 78 electrically connected to controllable and sensing components of the thermal management system 10. The controller 78 can be electrically connected to these components by way of, for example, conductive wires. A bus, such as controller area network (CAN) bus, may also be used. The controller 78 is described functionally as a single unit, however the controller 78 may be made up of a plurality of units that communicate with each other. The controller 78 includes at least one processor 166 that can execute instructions originating from memory 168 in the form of a program or routine, for example. Such instructions form logic that can be used by the controller 78 to control the thermal management system 10, as will now be described with reference to various configurations of controllable components of the thermal management system 10 described above. The term configuration as used in this disclosure refers to one or more settings of one or more components, such as the positions of valves, the speeds of pumps and fans, the current supplied to heaters, among others.

[0058] Also shown in Figure 3 is an ambient temperature sensor 180 that can be provided to the vehicle 12 at a position to sense a temperature of the environment around the vehicle 12.

[0059] The controller 78 can control the temperature of the motor circuit thermal load 61 by controlling the motor circuit pump 70 and the cabin heating circuit valve 88. The motor circuit thermal load 61 can be cooled by positioning the cabin heating circuit valve 88 in its second position to circulate heat exchange fluid between the motor circuit 56 and the cabin heating circuit 58. The cabin heating circuit pump 86 can be controlled to be off, and the flow rate of heat exchange fluid can be controlled by the motor circuit pump 70. Waste heat from the motor circuit thermal load 61 is thus used to heat the passenger cabin 18 via the cabin heating heat exchanger 47. If no further heat is needed for the cabin 18 (aside from the waste heat captured from the motor circuit thermal load 61), the heater 32 can remain off, thereby saving energy. Cooling the motor circuit thermal load 61 by heating the cabin 18 in this way may be referred to as a motor waste-heat recovery configuration.

[0060] The controller 78 can further control the temperature of the motor circuit thermal load 61 by further controlling components of the engine circuit 57, namely, the radiator bypass valve 75, the radiator fan 144, the engine circuit pump 79, and optionally, the internal combustion engine 21. As in the motor waste-heat recovery configuration, the heating circuit valve 88 may be positioned in its second position to circulate heat exchange fluid between the motor circuit 56 and the cabin heating circuit 58 using the motor circuit pump 70. The motor circuit thermal load 61 can then be cooled by running the engine circuit pump 79 and positioning the radiator bypass valve 75 in its first position to allow heat exchange fluid in the engine circuit 58 to cool at the radiator 64 before entering the heat exchanger 99 to cool heat exchange fluid flowing through the connected cabin heating circuit 58 and motor circuit 56. The motor circuit thermal load 61 is thus cooled by the radiator 64 via the heat exchanger 99. The fan 144 can be controlled to increase the cooling capacity of the radiator 64, and thus further cool heat exchange fluid on the motor circuit side of the heat exchanger 99. Cooling the motor circuit thermal load 61 using the radiator 64 in this way may be referred to as a motor-radiator cooling configuration. The controller 78 can also refrain from turning on the internal combustion engine 21 to temporarily prevent the engine 78 from generating heat that would reduce the amount of cooling available to motor circuit thermal load 61. Alternatively, instead of keeping the internal combustion engine 21 off in the motor-radiator cooling configuration, the controller 78 can opportunistically enter the motor-radiator cooling configuration when the internal combustion engine 21 is off for other reasons and then exit the motor-radiator cooling configuration when the internal combustion engine 21 turns on. However, the motor-radiator cooling configuration can cool the motor circuit thermal load 61 while the internal combustion engine 21 is running, though the amount of cooling provided will be less than when the engine 21 is off, all other factors being equal.

[0061] The controller 78 can isolate the motor circuit thermal load 61 from the cabin heating circuit 58 to avoid cooling the motor circuit thermal load 61 and/or for other reasons. This can be achieved by the controller 78 positioning the heating circuit valve 88 in its first position to isolate the motor circuit 56 from the cabin heating circuit 58. This may be referred to as a motor closed-loop configuration.

[0062] The controller 78 can select one of the above-described configurations for the motor circuit thermal load 61 with reference to a temperature sensed by the motor circuit temperature sensor 76. When the temperature of heat exchange fluid sensed by the motor circuit temperature sensor 76 reaches an upper threshold (e.g., 50 degrees Celsius), the controller 78 may be programmed to start cooling the motor circuit thermal load 61. When the temperature drops below a lower threshold (e.g., 46 degrees Celsius) the controller 78 may be programmed to stop cooling the motor circuit thermal load 61. When cooling is not required and there is no cabin heating demand, then the controller 78 has the valve 88 in the first position so that the motor circuit 56 is in the motor closed-loop configuration.

[0063] When cooling is required, the controller 78 can select the motor waste-heat recovery configuration or the motor-radiator cooling configuration based on one or more conditions that can include the amount, if any, of cabin heating being requested by the climate control system and a temperature sensed by the engine circuit temperature sensor 83. For example, if no or low cabin heating is being requested and the temperature sensed by the engine circuit temperature sensor 83 is low enough (e.g., 45 degrees Celsius) to allow the engine circuit 57 to cool the motor circuit thermal load 61, then the controller 78 can select the motor-radiator cooling configuration to cool the motor circuit thermal load 61 via the radiator 64. If significant cabin heating is being requested, then the controller 78 can select the motor waste-heat recovery configuration to use heat that would otherwise be wasted to heat the passenger cabin 18 via the cabin heating heat exchanger 47.

[0064] The controller 78 can control the temperature of the engine circuit thermal load 67 by controlling the engine circuit pump 79, the radiator bypass valve 75, and the radiator fan 144. The engine circuit thermal load 67 is cooled using both the radiator 64 and the heat exchanger 99, in an engine-radiator cooling configuration, or just using the heat exchanger 99, in an engine waste-heat recovery configuration, as determined by the position of the radiator bypass valve 75. The controller 78 can reference the temperature sensed by the engine circuit temperature sensor 83 to determine the amount of cooling required by the engine circuit thermal load 67. Accordingly, the controller 78 can increase the cooling effect of the radiator 64 by increasing the speed of the radiator fan 144. The controller 78 can decrease cooling to the engine circuit thermal load 67 by controlling the radiator bypass valve 75 to be in its second position so that flow of heat exchange fluid bypasses the radiator 64 and is cooled only at the heat exchanger 99. Bypassing the radiator 64 can be particularly effective when there is significant cabin heating demand, as heat from the engine circuit thermal load 67 can be imparted to the cabin heating circuit 58 via the heat exchanger 99. The controller 78 can specifically commence the engine waste-heat recovery configuration to increase heat provided to the heat exchanger 99 in response to cabin heating demand.

[0065] The controller 78 can coordinate cooling of the motor circuit thermal load 61 and the engine circuit thermal load 67, with reference to the demand placed on the cabin heating heat exchanger 47 for cabin heating. The aforementioned configurations can be coordinated as follows.

[0066] The motor waste-heat recovery configuration and the engine waste-heat recovery configuration can be used independently or together to meet the cabin heating demand and save energy in the form of heat that would otherwise be dissipated to the surrounding environment. The waste-heat recovery configurations can be used together, as heat exchange fluid heated by the motor circuit thermal load 61 can be heated further by the engine circuit thermal load 67 via the heat exchanger 99, since the engine 21 is expected to normally operate at temperatures higher than those at which the motor 14 normally operates. However, it may be desirable to avoid using the waste-heat recovery configurations together in situations where the engine circuit thermal load 67 would end up heating the motor circuit thermal load 61.

[0067] The motor closed-loop configuration can be used with either the engine waste-heat recovery configuration or the engine-radiator cooling configuration. When the motor circuit 56 is in the motor closed-loop configuration, the motor circuit 56 is isolated from the cabin heating circuit 58 and, accordingly, any heating of the heat exchange fluid in the cabin heating circuit 58 can only be a result of operation of the heat exchanger 99 and the heater 32.

[0068] The motor-radiator cooling configuration is used with the engine-radiator cooling configuration to allow heat from the motor circuit thermal load 61 to be dissipated at the radiator 64.

[0069] It should be noted that the heat exchanger 99 can be used to transfer heat in different directions depending on the configuration selected by the controller 78. For example, when the engine waste-heat recovery configuration is being used to heat the passenger cabin 18, the heat exchanger 99 transfers heat from the engine circuit 57 to the cabin heating circuit 58. When the motor-radiator cooling configuration is being used to cool the motor circuit thermal load 61, the heat exchanger 99 may transfer heat from the cabin heating circuit 58 to the engine circuit 57 if the engine 21 is off or in general if the engine circuit thermal load is cold 67.

[0070] Regarding cabin heating, the controller 78 responds to a heating demand indicated by the cabin climate control system, which can include buttons, dials, or any other suitable human-machine interface through which the operator of the vehicle can select how much heat, if any, should be provided to the passenger cabin 18. The controller 78 can determine whether any one or more of the motor waste-heat recovery configuration, the engine waste-heat recovery configuration, and the cabin heating circuit heater 32 should be used to meet the heating demand. The controller 78 can be configured to prioritize use of the waste-heat recovery configurations over use of the heater 32 in order to save energy. Which one or more of the waste-heat recovery configurations is selected can be based, at least in part, on the level of cabin heating demand and the ability of each of the waste-heat recovery configurations to meet the demand, as indicated by the temperatures sensed at sensors 76 and 83.

[0071] The controller 78 may have one cabin cooling configuration. The controller 78 determines if the actual temperature of the evaporator 48 is higher than the target temperature of the evaporator 48 by more than a calibrated amount. If so, then the controller 78 can turn on the compressor 30 and move the refrigerant flow control valve 138 to the open position so that refrigerant flows through the evaporator 48 to cool an air flow that is passed into the cabin 18. The controller 78 can adjust the speed of the compressor 30 based on the states of the flow control valves 138 and 140. The controller 78 can also cycle open and closed each of the flow control valves 138 and 140 to control refrigerant flow.

[0072] When the climate control system in the cabin 18 is set to a 'defrost' setting, the controller 78 will enter a defrost configuration, and will return to whichever heating or cooling configuration it was in once defrost is no longer needed.

[0073] The controller 78 can maintain the temperature of the battery packs 16a and 16b within a range that promotes efficiency and extends the life of the battery packs 16a and 16b. An example of such as range is 36 to 38 degrees Celsius. To maintain the battery packs 16a and 16b within this temperature range, the controller 78 can cool or heat the battery packs 16a and 16b, as will now be discussed.

[0074] The controller 78 may have two cooling configurations for cooling the battery circuit thermal load 96: cooling via the motor circuit 56 and cooling via the chiller 112. As a condition for cooling the battery circuit thermal load 96, the controller 78 determines whether the temperature sensed by the battery circuit temperature sensor 116 temperature exceeds an upper threshold (e.g., 38 degrees Celsius).

[0075] When cooling is required, the controller 78 determines whether the motor circuit 56 can be used to cool the battery circuit thermal load 96. Accordingly, the controller 78 determines whether the temperature sensed by the motor circuit temperature sensor 76 is lower than a lower threshold (e.g., 36 degrees Celsius) by a specific amount (e.g., 1 degree Celsius), which may, for example, be related to the expected temperature rise that would be incurred in the flow of fluid from the temperature sensor 76 to the battery circuit thermal load 96. If the temperature sensed by the motor circuit temperature sensor 76 is low enough, the controller 78 commences a first battery circuit cooling configuration, wherein the controller 78 positions the battery circuit valve 114 in its first position so that flow of heat exchange fluid is generated through the battery circuit 60 from the motor circuit 56, and the controller 78 puts the refrigerant flow control valve 140 in the closed position preventing refrigerant flow through the chiller 112. Further, the controller 78 can commence the motor-radiator cooling configuration or the motor waste-heat recovery configuration, so that the first battery circuit cooling configuration ultimately uses the radiator 64 or the cabin heating heat exchanger 47 to cool the battery circuit thermal load 96 via the motor circuit 56. When the motor waste-heat recovery configuration is used, heat from the battery circuit thermal load 96 is used to heat the passenger cabin 18, thereby saving the energy that would have been used by the heater 32 to heat the cabin 18.

[0076] When the controller 78 determines that the temperature sensed by the motor circuit temperature sensor 76 is not lower than the lower threshold (e.g., 36 degrees Celsius) by the specific amount (e.g., 1 degree Celsius), the controller determines that the motor circuit 56 cannot be used to cool the battery circuit thermal load 96 effectively. Accordingly, the controller 78 commences a second battery circuit cooling configuration, wherein the controller 78 positions the battery circuit valve 114 in the second position and turns on the pump 106, so that flow in the battery circuit 60 is isolated from flow in the motor circuit 56. The controller 78 additionally positions the flow control valve 140 in the open position so that refrigerant flows through the chiller 112 to cool the flow in the battery circuit 60.

[0077] Using the motor circuit 56, and ultimately the radiator 64 or cabin heating heat exchanger 47, to cool the battery circuit thermal load 96 can reduce the need to use the relatively more energy-expensive chiller 112 for this purpose, and as such can conserve energy. Accordingly, the controller 78 can be configured to favor the first battery circuit cooling configuration when permitted by other operations in the thermal management system 10.

[0078] It will be understood that in any of the battery circuit cooling configurations, the controller 78 turns off the battery circuit heater 108.

[0079] The controller 78 may have four heating configurations for heating the battery circuit thermal load 96: heating by the motor circuit 56, heating by the battery circuit heater 108, heating by the motor circuit 56 and the battery circuit heater 108, and heating by the engine circuit 58 via the cabin heating circuit 58 and motor circuit 56. As a condition for heating the battery circuit thermal load 96, the controller 78 determines whether the temperature sensed by the battery circuit temperature sensor 116 temperature is lower than a lower threshold, such as the same lower threshold referenced for cooling (e.g., 36 degrees Celsius).

[0080] When heating is required, the controller 78 determines whether the motor circuit 56 can be used to heat the battery circuit thermal load 96. Accordingly, the controller 78 determines whether the temperature sensed by the motor circuit temperature sensor 76 is higher than an upper threshold (e.g., 38 degrees Celsius) by a specific amount (e.g., 1 degree Celsius), which may, for example, be related to the expected temperature drop of the fluid as it flows from the temperature sensor 76 to the battery circuit thermal load 96. The upper threshold for heating can be the same as the upper threshold for cooling, or it can be different. If the temperature sensed by the motor circuit temperature sensor 76 is high enough, the controller 78 commences a first battery circuit heating configuration, wherein the controller 78 positions the battery circuit valve 114 in its first position so that flow of heat exchange fluid is generated through the battery circuit 60 from the motor circuit 56. Additionally, the controller 78 turns off the battery circuit heater 32. The controller 78 can further operate the motor circuit 56 in any of its configurations based on considerations of those configurations. For instance, when in the motor waste-heat recovery configuration, at least some of the heat that would be destined for the cabin 18 is used to heat the battery circuit thermal load 96. When in the motor-radiator cooling configuration, heating the battery circuit thermal load 96 can increase the speed at which the motor circuit thermal load 61 is cooled. Lastly, the motor circuit closed-loop configuration used in conjunction with the first battery circuit heating configuration provides an additional way to cool the motor circuit thermal load 61 in circumstances, for example, in which the motor waste-heat recovery configuration and motor-radiator cooling configuration are less desirable to use.

[0081] In a situation where the engine 21 is off, the controller 78 determines that the battery packs 16 require heating, and the controller 78 determines that the fluid in the motor circuit 56 would not be useful, then the controller 78 may be programmed to use the battery circuit heater 108 to heat fluid circulating in the battery circuit 60 so as to heat the battery circuit thermal load 96. Thus, in this case, the controller 78 commences the battery circuit heating configuration wherein the controller 78 positions the battery circuit valve 114 in the second position and turns on the pump 106, so that flow in the battery circuit 60 is isolated from the cooler flow in the motor circuit 56. The controller 78 additionally turns on the battery circuit heater 108 to heat the flow in the battery circuit 60. Since the battery circuit 60 is isolated from the motor circuit 56, the configuration of the motor circuit 56 need not be considered.

[0082] If the controller 78 determines that the motor circuit 56 is not hot enough to heat the battery circuit thermal load 96 to an acceptable temperature by itself, but can still contribute to heating the battery circuit thermal load 96 because it is hotter than the battery circuit thermal load 96, the controller 78 can use both the motor circuit 56 and the battery circuit heater 108 to heat the battery circuit thermal load 96 to an acceptable temperature. In this case, the controller 78 operates in a third battery circuit heating configuration wherein the controller 78 positions the battery circuit valve 114 in the first position, so that fluid flows between from the motor circuir 56 through the battery circuit 60 and back into the motor circuit 56. In addition, the controller 78 turns on the battery circuit heater 108. Since the motor circuit thermal load 61 is only partially contributing to heating the battery circuit thermal load 96, it may in some instances be desirable to use the third battery circuit heating configuration in conjunction with the motor circuit closed-loop configuration, so that other sources of cooling (i.e., the cabin heating heat exchanger 47 and the radiator 64) will not simultaneously pull heat from the motor circuit thermal load 61.

[0083] The fourth battery circuit heating configuration can be used in some situations, including a situation where fluid in the motor circuit 56 is not hot enough to heat the battery packs 16 to an acceptable temperature but the engine circuit thermal load 67 is sufficiently hot that it can be used to heat the battery packs 16 to an acceptable temperature. In the fourth battery circuit heating configuration, the motor and engine circuits 56 and 57 are put in their waste-heat recovery configurations, so that the motor circuit 56 is in communication with the heat exchanger 99 and so that the engine circuit 57 bypasses the radiator 64. Additionally, the battery circuit valve 114 is positioned in its first position to join the motor circuit 56 and the battery circuit 60. Since the fluid in the engine circuit 57 is hotter than the fluid in the motor circuit 56, heat will flow across the heat exchanger 99 from the engine circuit 57 to the motor circuit 56 (via the heat exchanger 99) to heat the heat exchange fluid in the motor circuit 56, which will then be circulated through the battery circuit 60 to heat the battery circuit thermal load 96 (and the battery packs 16 in particular). Thus, waste heat from the engine circuit 57 can be transferred to the battery circuit thermal load 96 via the heat exchanger 99, the cabin heating circuit 58, and the motor circuit 56. Using waste heat from the engine circuit 57 can save energy by reducing the need to use the battery heater 108. One consideration that the controller 78 can take into account when determining whether the fourth battery circuit heating configuration should be used over the second battery circuit heating configuration, is the amount, if any, of cabin heating demand, which may require that all or most of the waste heat from the engine circuit 57 be used to heat the passenger cabin 18 rather than the battery circuit thermal load 96.

[0084] It will be understood that in any of the battery circuit heating configurations, the controller 78 turns off the chiller 112.

[0085] Heating and cooling configurations for the motor circuit 56, the engine circuit 57, the cabin heating circuit 58, and the battery circuit 60, including those discussed above, are shown schematically in Figures 6a-h. Figures 6a-h indicate the positions of the valves 75, 88, and 114, as well as the general expected tendency of heat flow among the motor circuit 56, the engine circuit 57, the cabin heating circuit 58, and the battery circuit 60, as indicated by arrows, at least in some situations. Double-headed arrows indicate that in some situations the flow of heat is in one direction (i.e. from a first circuit to a second circuit) and in other situations the flow of heat is the reverse (i.e. from the second circuit to the first circuit). No arrow indicates no appreciable heat flow. The heat flows represented in Figures 6a-h are based on situations wherein the pumps 70, 79, 86, and 106 operate as discussed above and that heaters 32 and 108 are not operated.

[0086] Moreover, as mentioned above, the first position of valve 88 isolates the motor circuit 56 from the cabin heating circuit 58, while the second position of valve 88 connects the motor circuit 56 to the cabin heating circuit 58. The first position of the valve 75 connects the radiator 64 to the engine circuit 57, while the second position of the valve 75 bypasses the radiator 64. Finally, the first position of the valve 114 connects the battery circuit 60 to the motor circuit 56, while the second position of the valve 114 isolates the battery circuit from the motor circuit 56.

[0087] Figures 6a-h illustrate generally expected heat flows for illustrative purposes in certain situations, however the heat flows may be different under certain circumstances.

[0088] Figure 6a shows the first or third battery circuit heating configuration heating the battery packs 16a and 16b with the motor circuit closed-loop configuration or the first battery circuit cooling configuration cooling the battery packs 16a and 16b with the motor circuit closed-loop configuration, depending on the relative temperatures of the motor circuit 56 and battery circuit 60. Figure 6a also shows a configuration in which the engine circuit 57 can heat or cool the cabin heating circuit 58 via the heat exchanger 99 depending on the relative temperatures of these circuits 57 and 58.

[0089] Figure 6b shows the motor circuit closed-loop configuration, as well as the configuration of Figure 6a in which the engine circuit 57 can heat or cool the cabin heating circuit 58.

[0090] Figure 6c shows the first or third battery circuit heating configuration heating the battery packs 16a and 16b with the motor circuit closed-loop configuration or the first battery circuit cooling configuration cooling the battery packs 16a and 16b with the motor circuit closed-loop configuration, depending on the relative temperatures of the motor circuit 56 and battery circuit 60. Figure 6c also shows the engine waste-heat recovery configuration being used to heat the passenger cabin 18.

[0091] Figure 6d shows the motor circuit closed-loop configuration, as well as the engine waste-heat recovery configuration being used to heat the passenger cabin 18.

[0092] Figure 6e shows the motor-radiator cooling configuration, as well as the first or third battery circuit heating configuration.

[0093] Figure 6f shows the motor-radiator cooling configuration.

[0094] Figure 6g shows the fourth battery circuit heating configuration using the engine waste-heat recovery configuration to heat the battery packs 16a and 16b.

[0095] Figure 6h shows the engine waste-heat recovery configuration as well as the motor waste-heat recovery configuration. The direction of heat flow between the motor circuit 56 and the cabin heating circuit 58 depends on the heating demand at the cabin 18.

[0096] The logic used by the controller 78 to control the operation of the thermal management system 10 can be configured to depend on which of several states the vehicle is in. The vehicle 12 may be on-plug and off, which means that the vehicle itself is off (e.g., the ignition key is out of its slot in the instrument panel) and is plugged into the external electrical source 44 (e.g., for recharging the battery packs 16a and 16b). The vehicle may be off-plug and off, which means that the vehicle itself is off and is not plugged into the external electrical source 44. The vehicle may be off-plug and on, which means that the vehicle itself is on and is not plugged into the external electrical source 44. The controller 78 can take into account the on-plug or off-plug state of the vehicle when determining which of the above-described heating or cooling configurations to use. For example, when the vehicle 12 is on-plug and off, the motor circuit thermal load 61 is not expected to significantly increase in temperature, so the controller 78 may not need to consider using the motor-radiator cooling configuration.

[0097] In some embodiments, the vehicle may lack the capability to be plugged into an external electrical source for charging the battery. In such embodiments, the vehicle would charge the battery via the engine 21. In such embodiments the vehicle would never therefore be on-plug.

[0098] In the event of an emergency battery shutdown, the controller 78 may be programmed to shut off the compressor 30 and turn on the cabin heating circuit heater 32 so as to bleed any residual voltage.

[0099] Reference is made to Figure 4, which shows a schematic illustration of a thermal management system 200 for a vehicle 12 in accordance with another embodiment of the present invention. Features and aspects of the other embodiments described herein can be used with this embodiment. Like reference numerals (i.e., identical numerals and those that are identical when ignoring the leading "2") denote like elements. Redundant description is omitted for clarity. The description of the other embodiments can be referenced for like elements.

[00100] A power electronics cooling circuit 256 includes the DC/DC converter 34 and the transmission control module 28, which generate heat during operation and thus form an power electronics cooling circuit thermal load 261. The conduits 66 and 68, the pump 70, and the valve 88 are arranged as discussed above, except that an power electronics cooling circuit thermal load outlet 265 is located at the transmission control module 28. The power electronics cooling circuit 256 does not include the electric traction motor 14, although the motor 14 is still electrically connected to the transmission control module 28 to drive the vehicle 12.

[00101] The electric traction motor 14 joins the internal combustion engine 21 in a second or engine-motor circuit 257. The motor 14 and engine 21 form an engine-motor thermal load 267 with an engine-motor circuit thermal load inlet 269 at the motor 14. In this embodiment, the motor 14 is positioned upstream of the engine 21, so that the motor 14 receives heat exchange fluid that is cooler than that provided to the engine 21. This is because the motor 14 has a lower maximum acceptable working temperature, which can, for example, be about 100 degrees Celsius with temporary excursions up to 140 degrees Celsius permitted.

[00102] The controller 78 can use the heating and cooling configurations as described for the embodiment shown in Figure 2, with the following differences. The motor waste-heat recovery configuration described in relation to Figure 2, may be referred to as the power electronics waste-heat recovery configuration in relation to Figure 4. In this configuration, waste heat from the DC/DC converter 34 and the transmission control module 28 is used to heat the cabin 18 via the cabin heating heat exchanger 47. The motor-radiator cooling configuration described above may be referred to as the power electronics-radiator cooling configuration in relation to Figure 4, wherein the heat exchanger 99 draws heat from the power electronics cooling circuit 256 via the cabin heating circuit 58 to ultimately be dissipated at the radiator 64. The motor closed-loop configuration may be referred to as the power electronics closed-loop configuration in relation to Figure 4, wherein the power electronics cooling circuit 256 is isolated from the cabin heating circuit 58. The engine waste-heat recovery configuration described above may be referred to as the engine-motor waste-heat recovery configuration in relation to Figure 4, wherein waste heat from both the engine 21 and the motor 14 is used to heat the cabin via the heat exchangers 99 and 47. The engine-radiator cooling configuration may be referred to as the engine-motor radiator cooling configuration in relation to Figure 4, in which the engine 21 and motor 14 are both cooled using the radiator 64. Regarding these configurations, the example temperature thresholds may be the same as described for the embodiment of Figure 2, or they may be different. Figures 6a-h also apply to this embodiment.

[00103] An advantage of including the motor 14 in the same heat exchange fluid circuit as the engine 21 is that the motor 14 can withstand higher temperatures than the DC/DC converter 34 and the transmission control module 28. The motor 14 has a maximum acceptable operating temperature (e.g., about 100 degrees Celsius) that is closer to the normal operating temperature of the engine 21 (e.g., about 120 degrees Celsius) than to the maximum acceptable operating temperature (e.g., about 75 degrees Celsius) of the DC/DC converter 34 and transmission control module 28.

[00104] In any of the embodiments, the controller 78 can be programmed with the following high-level objectives and strategies for using the above described configurations. The high level objectives include:

[00105] A. control the components related to heating and cooling of the battery circuit thermal load 96 to maintain the battery packs 16a and 16b and the battery charge control module 42 within the optimum temperature range during charging and vehicle operation;

[00106] B. maintain the motor 14, the transmission control module 28 and the DC/DC converter 34 at their optimum temperature ranges;

[00107] C. control the components related to heating and cooling the cabin 18 based on input from the climate control system;

[00108] D. operate with a goal of maximizing vehicle range while meeting vehicle system requirements;

[00109] E. maintain the engine 21 in its optimum temperature range; and

[00110] F. use waste heat from the motor 14 and the engine 21 to heat the passenger cabin 18.

[00111] The controller 78 may use the following high-level strategy on-plug:

[00112] When the vehicle is on-plug and is off, the controller 78 pre-conditions the battery packs 16a and 16b if required. Pre-conditioning entails bringing the battery packs 16a and 16b into a temperature range wherein the battery packs 16a and 16b are able to charge more quickly.

[00113] The controller 78 determines the amount of power available from the external electrical source for temperature control of the battery packs 16a and 16b, which is used to determine the maximum permitted compressor speed, maximum fan speed or the battery pack heating requirements depending on whether the battery packs 16a and 16b require cooling or heating. A calibratible hysteresis band will enable the battery pack temperature control to occur in a cyclic manner if the battery pack temperatures go outside of the selected limits (which are shown in Figure 5). If sufficient power is available from the electrical source, the battery packs 16a and 16b may be charged while simultaneously being conditioned (i.e., while being cooled or heated to remain within their selected temperature range). If the battery packs 16a and 16b reach their fully charged state, battery pack conditioning may continue, so as to bring the battery packs 16a and 16b to their selected temperature range for efficient operation.

[00114] When the vehicle is on-plug the battery circuit heater 108 may be used to bring the battery packs 16a and 16b up to a selected temperature range, as noted above. In one of the heating configurations described above for the battery circuit 60, the battery circuit valve 114 is in the second position so that the flow in the battery circuit 60 is isolated from the flow in the motor circuit 56, and therefore the battery circuit heater 108 only has to heat the fluid in the battery circuit 60.

[00115] The cabin may be pre-conditioned (i.e., heated or cooled while the vehicle is off) when the vehicle is on-plug and the state of charge of the battery packs 16a and 16b is greater than a selected value.

[00116] If the vehicle is started while on-plug, the controller 78 may continue to condition the battery packs 16a and 16b, to cool the motor circuit thermal load 61 and use of the HVAC system 46 for both heating and cooling the cabin 18 may be carried out.

[00117] When the vehicle is off-plug, battery pack heating may be achieved solely by using the heat in the fluid from the motor circuit (i.e., without the need to activate the battery circuit heater 108). Thus, while the vehicle is off-plug and on and the battery packs 16a and 16b require heating, the battery circuit valve 114 may be in the first position so that the battery circuit 60 is not isolated from the motor circuit 56. Some flow may pass through the third battery circuit conduit 110 for flow balancing purposes, however the refrigerant flow to the chiller 112 is prevented while the battery packs 16a and 16b require heating. By using low-voltage battery circuit heaters instead of high-voltage heaters for the heaters 108, a weight-savings is achieved which thereby extends the range of the vehicle.

[00118] When the vehicle is off-plug, battery pack cooling may be achieved by isolating the battery circuit 60 from the motor circuit 56 by moving the battery circuit valve 114 to the second position and by opening the flow of refrigerant to the chiller 112 by moving the flow control valve 140 to its open position, and by running the compressor 30, as described above in one of the two cooling configurations for the battery circuit 60.

[00119] It will be noted that the battery packs 16a and 16b may sometimes reach different temperatures during charging or vehicle operation. The controller 78 may at certain times request isolation of the battery circuit 60 from the motor circuit 56 and may operate the battery circuit pump 106 without operating the heater 108 or permitting refrigerant flow to the chiller 112. This will simply circulate fluid around the battery circuit 60 thereby balancing the temperatures between the battery packs 16a and 16b.

[00120] Reference is made to Figure 5, which shows a graph of battery pack temperature vs. time for a particular example of a battery pack, to highlight several of the rules which the controller 78 (Figure 3) follows in certain embodiments. In situations where the vehicle is on-plug and the battery packs 16a and 16b are below a selected minimum charging temperature Tcmin (Figure 5), the controller 78 will heat the battery packs 16a and 16b prior to charging them. Once the battery packs 16a and 16b reach the minimum charging temperature Tcmin, some of the power from the electrical source may be used to charge the battery packs 16a and 16b, and some of the power from the electrical source may continue to be used to heat them. When the battery packs 16a and 16b reach a minimum charge only temperature Tcomin, the controller 78 may stop using power from the electrical source to heat the battery packs 16a and 16b and may thus use all the power from the electrical source to charge them. Tcmin may be, for example, -35 degrees Celsius and Tcomin may be, for example, -10 degrees Celsius.

[00121] While charging, the controller 78 may precondition the battery packs 16a and 16b for operation of the vehicle. Thus, the controller 78 may bring the battery packs 16a and 16b to a desired minimum operating temperature Tomin while on-plug and preferably during charging.

[00122] In situations where the vehicle is on-plug and the battery packs 16a and 16b are above a selected maximum charging temperature Tcmax, the controller 78 will cool the battery packs 16a and 16b prior to charging them. Once the battery packs 16a and 16b come down to the maximum charging temperature Tcmax power from the electrical source may be used to charge them, while some power may be required to operate the compressor 30 and other components in order to maintain the temperatures of the battery packs 16a and 16b below the temperature Tcmax. Tcmax may be, for example, 30 degrees Celsius.

[00123] The battery packs 16a and 16b may have a maximum operating temperature Tomax that is the same or higher than the maximum charging temperature Tcmax. As such, when the battery packs 16a and 16b are cooled sufficiently for charging, they are already pre-conditioned for operation. In situations where the maximum operating temperature Tomax is higher than the maximum charging temperature Tcmax, the temperatures of the battery packs 16a and 16b may be permitted during operation after charging to rise from the temperature Tcmax until they reach the temperature Tomax.

[00124] The maximum and minimum operating temperatures Tomax and Tomin define a preferred operating range for the battery packs 16a and 16b. In situations where the battery packs 16a and 16b are below minimum operating temperature or above their maximum operating temperature, the vehicle may still be used to some degree. Within selected first ranges shown at 150 and 152 (based on the nature of the battery packs 16a and 16b) above and below the preferred operating range the vehicle may still be driven, but the power available will be somewhat limited. Within selected second ranges shown at 154 and 156 above and below the selected first ranges 150 and 152, the vehicle may still be driven in a limp home mode, but the power available will be more severely limited. Above and below the selected second ranges, the battery packs 16a and 16b cannot be used. The lower first range 150 may be between about 10 degrees Celsius and about -10 degrees Celsius and the upper first range 152 may be between about 35 degrees Celsius and about 45 degrees Celsius. The lower second range 154 may be between about -10 degrees Celsius and about -35 degrees Celsius. The upper second range may be between about 45 degrees Celsius and about 50 degrees Celsius.

[00125] An advantage of the thermal management systems 10 and 200 is that they are readily adaptable to vehicles originally designed to use only internal combustion engines. That is, existing internal combustion engine vehicle designs can be reconfigured as hybrid designs by, for example, replacing the larger, original internal combustion engine with the smaller, range-extending engine 21, adding the motor 14, battery packs 14a and 14b, and their supporting components, adding the cabin heater 32 and heat exchanger 99, and adding an additional expansion tank 124a. The HVAC system 46, compressor 30, and condenser 122, radiator 64, and fan 144 package can all remain as originally designed. This can lead to more efficient use of existing design and manufacturing resources.

[00126] It will be noted that the pumps 70, 79, 86 and 106 are preferably variable flow rate pumps. In this way they can be used to adjust the flow rates of the heat exchange fluid through the circuits 56, 57, 58, and 60. By controlling the flow rate generated by the pumps 70, 79, 86 and 106, the amount of energy expended by the thermal management system 10 can be adjusted in relation to the level of criticality of the need to change the temperature in one or more of the thermal loads.

[00127] Additionally, the compressor 30 is also capable of variable speed control so as to meet the variable demands of the HVAC system 46 and the battery circuit 60.

[00128] Throughout this disclosure, the controller 78 is referred to as turning on devices (e.g., the battery circuit heater 108, the chiller 112), turning off devices, or moving devices (e.g., valve 88) between a first position and a second position. It will be noted that, in some situations, the device will already be in the position or the state desired by the controller 78, and so the controller 78 will not have to actually carry out any action on the device. For example, it may occur that the controller 78 determines that the battery heater 108 needs to be turned on. However, the heater 108 may at that moment already be on based on a prior decision by the controller 78. In such a scenario, the controller 78 obviously does not actually 'turn on' the heater 108, even though such language is used throughout this disclosure. For the purposes of this disclosure and claims, the concepts of turning on, turning off and moving devices from one position to another are intended to include situations wherein the device is already in the state or position desired and no actual action is carried out by the controller 78 on the device.

[00129] In this disclosure the use of an evaporator was described for cooling the air flow to the cabin 18 and a chiller was described for cooling the coolant in the battery circuit. It will be understood that the chiller is a first heat exchanger and may be replaced by any other suitable type of heat exchanger, (e.g. a different type of heat exchanger that still uses refrigerant), and similarly the evaporator is a second heat exchanger and may be replaced by any other suitable type of heat exchanger, (e.g. a different type of heat exchanger that still uses refrigerant).

[00130] In addition, terms such as heat, heating, cool, and cooling are used in this disclosure to describe the transfer of heat. Use of one term over another is not intended to be limiting, and heating in one direction can be taken to be equivalent to cooling in the opposite direction.

[00131] According to one aspect of this disclosure, a method of heating a vehicle passenger cabin of a vehicle includes heating heat exchange fluid with an electric traction motor of the vehicle, heating heat exchange fluid with a range extending device (such as, for example, an internal combustion engine or a fuel cell) of the vehicle, providing heat from the heat exchange fluid heated by the electric traction motor to a passenger cabin heating heat exchanger, providing heat from the heat exchange fluid heated by the range extending device to the passenger cabin heating heat exchanger.

[00132] Providing heat from the heat exchange fluid heated by the range extending device to the passenger cabin heating heat exchanger can include using a liquid-to-liquid heat exchanger to transfer heat from the heat exchange fluid heated by the range extending device to heat exchange fluid flowing to the passenger cabin heating heat exchanger.

[00133] The heat exchange fluid flowing to the passenger cabin heating heat exchanger can include the heat exchange fluid heated by the electric traction motor.

[00134] The heat exchange fluid heated by the range extending device can include the heat exchange fluid heated by the electric traction motor.

[00135] Providing heat from the heat exchange fluid heated by the electric traction motor and the range extending device to the passenger cabin heating heat exchanger can include using a liquid-to-liquid heat exchanger to transfer heat from the heat exchange fluid heated by the electric traction motor and the int range extending device to heat exchange fluid flowing to the passenger cabin heating heat exchanger.

[00136] The method can further include heating heat exchange fluid with at least one of a transmission control module and a DC/DC converter of the vehicle, and providing heat from the heat exchange fluid heated by the at least one of the transmission control module and the DC/DC converter to the passenger cabin heating heat exchanger.

[00137] According to another aspect of this disclosure, a method of cooling electrical components of a vehicle includes circulating heat exchange fluid through a circuit including a range extending device (such as, for example, an internal combustion engine or a fuel cell), a radiator, and a liquid-to-liquid heat exchanger. The method further includes cooling the circulating heat exchange fluid using the radiator, cooling heat exchange fluid heated by at least one of a transmission control module and a DC/DC converter using the liquid-to-liquid heat exchanger, circulating the heat exchange fluid cooled by the liquid-to-liquid heat exchanger through the at least one of the transmission control module and the DC/DC converter.

[00138] The method can further include cooling heat exchange fluid heated by an electric traction motor using the liquid-to-liquid heat exchanger, and circulating the heat exchange fluid cooled by the liquid-to-liquid heat exchanger through the electric traction motor.

[00139] The circuit can further include an electric traction motor.

[00140] According to another aspect of this disclosure, a thermal management system for a vehicle includes a passenger cabin heating circuit configured to circulate heat exchange fluid through a liquid-to-liquid heat exchanger and a passenger cabin heating heat exchanger. The thermal management system further includes a second circuit configured to circulate heat exchange fluid through a range extending device (such as, for example, an internal combustion engine or a fuel cell), a radiator, and the liquid-to-liquid heat exchanger. The liquid-to-liquid heat exchanger is configured to transfer heat between heat exchange fluid of the passenger cabin heating circuit and heat exchange fluid of the second circuit.

[00141] The system can further include a motor circuit configured to circulate heat exchange fluid through an electric traction motor. The motor circuit can be selectably connected to the passenger cabin heating circuit by a valve.

[00142] The system can further include a battery circuit configured to circulate heat exchange fluid through a battery pack. The battery circuit can be selectably connected to the motor circuit by another valve.

[00143] The motor circuit can be further configured to circulate heat exchange fluid through at least one of a transmission control module and a DC/DC converter.

[00144] The system can further include an power electronics cooling circuit configured to circulate heat exchange fluid through at least one of a transmission control module and a DC/DC converter. The power electronics cooling circuit can be selectably connected to the passenger cabin heating circuit by a valve.

[00145] The second circuit can be further configured to circulate heat exchange fluid through an electric traction motor.

[00146] The system can further include a cabin heating circuit pump positioned at the cabin heating circuit.

[00147] The system can further include a second pump positioned at the second circuit.

[00148] According to another aspect of this disclosure, a method of heating a battery pack of a vehicle having an electric traction motor is provided. The method includes heating heat exchange fluid with a range extending device (such as, for example, an internal combustion engine or a fuel cell) of the vehicle, providing heat from the heat exchange fluid heated by the range extending device to a heat exchanger, and transferring heat using the heat

exchanger to heat exchange fluid circulating through a battery circuit coupled to the battery pack.

[00149] The method can further include heating the heat exchange fluid circulating through a battery circuit using the electric traction motor.

[00150] For greater certainty, throughout this disclosure, where an internal combustion engine has been described it will be understood that some other range extending device could be used instead, such as, for example, a fuel cell.

[00151] While the above description constitutes a plurality of embodiments of the present disclosure, it will be appreciated that the present disclosure is susceptible to further modification and change without departing from the fair meaning of the accompanying claims.

CLAIMS:

1. A method of heating a vehicle passenger cabin of a vehicle, the method comprising:

a) heating heat exchange fluid with an electric traction motor of the vehicle and with a range extending device of the vehicle; and

b) heating the vehicle passenger cabin using the heat exchange fluid.

2. The method of claim 1, wherein the heat exchange fluid is a first heat exchange fluid, and step a) includes:

c) heating a second heat exchange fluid with the range extending device; and

d) heating the first heat exchange fluid with the second heat exchange fluid.

3. The method of claim 2, wherein step d) includes passing the first and second heat exchange fluids through a liquid-to-liquid heat exchanger.

4. The method of claim 1, wherein the heat exchange fluid flows through the motor and through the range extending device.

5. The method of claim 4, wherein the heat exchange fluid is a first heat exchange fluid, and wherein step a) includes:

f) heating a second heat exchange fluid with the motor and with the range extending device; and

g) heating the first heat exchange fluid with the second heat exchange fluid.

6. The method of claim 1, further comprising:

i) heating the heat exchange fluid with at least one of a transmission control module of the vehicle and a DC/DC converter of the vehicle; and

j) heating the vehicle passenger cabin using the heat exchange fluid.

7. The method of claim 1, wherein the range extending device is an internal combustion engine.

8. A thermal management system for a vehicle, the system comprising:

a passenger cabin heating circuit configured to circulate heat exchange fluid through a liquid-to-liquid heat exchanger and a passenger cabin heating heat exchanger; and

a second circuit configured to circulate heat exchange fluid through a range extending device, a radiator, and the liquid-to-liquid heat exchanger,

wherein the liquid-to-liquid heat exchanger is configured to transfer heat between heat exchange fluid of the passenger cabin heating circuit and heat exchange fluid of the second circuit.

9. The system of claim 8, further comprising a motor circuit configured to circulate heat exchange fluid through an electric traction motor, the motor circuit being selectably connected to the passenger cabin heating circuit by a cabin heating circuit valve.

10. The system of claim 9, further comprising a battery circuit configured to circulate heat exchange fluid through a battery pack, the battery circuit being selectably connected to the motor circuit by a battery circuit valve.

11. The system of claim 9, wherein the motor circuit is further configured to circulate heat exchange fluid through at least one of a transmission control module and a DC/DC converter.

12. The system of claim 8, further comprising a power electronics cooling circuit configured to circulate heat exchange fluid through at least one of a transmission control module and a DC/DC converter, the power electronics cooling circuit being selectably connected to the passenger cabin heating circuit by a cabin heating circuit valve.

13. The system of claim 8, wherein the second circuit includes an electric traction motor.

14. The system of claim 8, further comprising a cabin heating circuit pump positioned to circulate heat exchange fluid through the cabin heating circuit.

15. The system of claim 8, further comprising a second pump positioned at the second circuit.

16. The system of claim 8, wherein the range extending device is an internal combustion engine.

17. A method of heating a battery pack of a vehicle having an electric traction motor, the method comprising:

heating heat exchange fluid with a range extending device of the vehicle;

providing heat from the heat exchange fluid heated by the range extending device to a heat exchanger; and

transferring heat using the heat exchanger to heat exchange fluid circulating through a battery circuit that includes the battery pack.

18. The method of claim 17, further comprising heating the heat exchange fluid circulating through a battery circuit using the electric traction motor.

19. The method of claim 17, wherein the range extending device is an internal combustion engine.

AMENDED CLAIMS

received by the International Bureau on 09 August 2013 (09.08.13)

1. A method of heating a vehicle passenger cabin and a battery pack of a vehicle, the method comprising:

a) heating heat exchange fluid with an electric traction motor of the vehicle and with a range extending device of the vehicle;

b) providing heat exchange fluid heated by the electric traction motor and the range extending device to a heat exchanger;

c) heating the vehicle passenger cabin using the heat exchange fluid from the heat exchanger;

d) providing heat from the range extending device to the electric traction motor via the heat exchanger; and

e) directing heat exchange fluid from the electric traction motor to a battery pack of the vehicle.

2. The method of claim 1, wherein the heat exchange fluid is a first heat exchange fluid, and step a) includes:

f) heating a second heat exchange fluid with the range extending device; and

g) heating the first heat exchange fluid with the second heat exchange fluid.

3. The method of claim 2, wherein step g) includes h) passing the first and second heat exchange fluids through the heat exchanger, and wherein the heat exchanger is a liquid-to-liquid heat exchanger.

4. The method of claim 1, wherein the heat exchange fluid flows through the motor and through the range extending device.

5. The method of claim 4, wherein the heat exchange fluid is a first heat exchange fluid, and wherein step a) includes:

i) heating a second heat exchange fluid with the motor and with the range extending device; and

j) heating the first heat exchange fluid with the second heat exchange fluid.

6. The method of claim 1, further comprising:

k) heating the heat exchange fluid with at least one of a transmission control module of the vehicle and a DC/DC converter of the vehicle; and

l) heating the vehicle passenger cabin using the heat exchange fluid of step k).

7. The method of claim 1, wherein the range extending device is an internal combustion engine.

8. A thermal management system for a vehicle, the system comprising:

a passenger cabin heating circuit configured to circulate heat exchange fluid through a heat exchanger;

a second circuit configured to circulate heat exchange fluid through a range extending device and the heat exchanger;

a third circuit including an electric traction motor and being configured to circulate heat exchange fluid through the electric traction motor and to the heat exchanger, wherein the third circuit is a motor circuit or a power electronics cooling circuit;

wherein the heat exchanger is configured to transfer heat between heat exchange fluid of the passenger cabin heating circuit and heat exchange fluid of the second circuit and from heat exchange fluid of the second circuit to heat exchange fluid of the third circuit; and

a battery circuit including a battery pack and being connected to the third circuit by a battery circuit valve for receiving heat exchange fluid from the third circuit and circulating heat exchange fluid to heat the battery pack.

9. The system of claim 8, further comprising the third circuit being the motor circuit, and the motor circuit being selectably connected to the passenger cabin heating circuit by a cabin heating circuit valve.

10. The system of claim 9, further comprising the battery circuit being selectably connected to the motor circuit by the battery circuit valve.

11. The system of claim 9, wherein the motor circuit is further configured to circulate heat exchange fluid through at least one of a transmission control module and a DC/DC converter.

12. The system of claim 8, further comprising the third circuit being the power electronics cooling circuit, and the power electronics cooling circuit being further configured to circulate heat exchange fluid through at least one of a transmission control module and a DC/DC converter, the power electronics cooling circuit being selectably connected to the passenger cabin heating circuit by a cabin heating circuit valve.

13. The system of claim 8, wherein the second circuit includes the electric traction motor.

14. The system of claim 8, further comprising a cabin heating circuit pump positioned to circulate heat exchange fluid through the cabin heating circuit.

15. The system of claim 8, further comprising a second pump positioned at the second circuit.

16. The system of claim 8, wherein the range extending device is an internal combustion engine.

17. The method of claim 1, further comprising circulating heat exchange fluid through a battery circuit including the battery pack and heating the heat exchange fluid circulating through the battery circuit using the electric traction motor.

18. The method of claim 1, further comprising directing the heat exchange fluid from the range extending device through a radiator and towards the heat exchanger.

19. The method of claim 1, further comprising directing the heat exchange fluid from the range extending device towards the heat exchanger and bypassing a radiator.

20. The system of claim 8, wherein the second circuit includes a radiator for circulating the heat exchange fluid and directing the heat exchange fluid towards the heat exchanger.

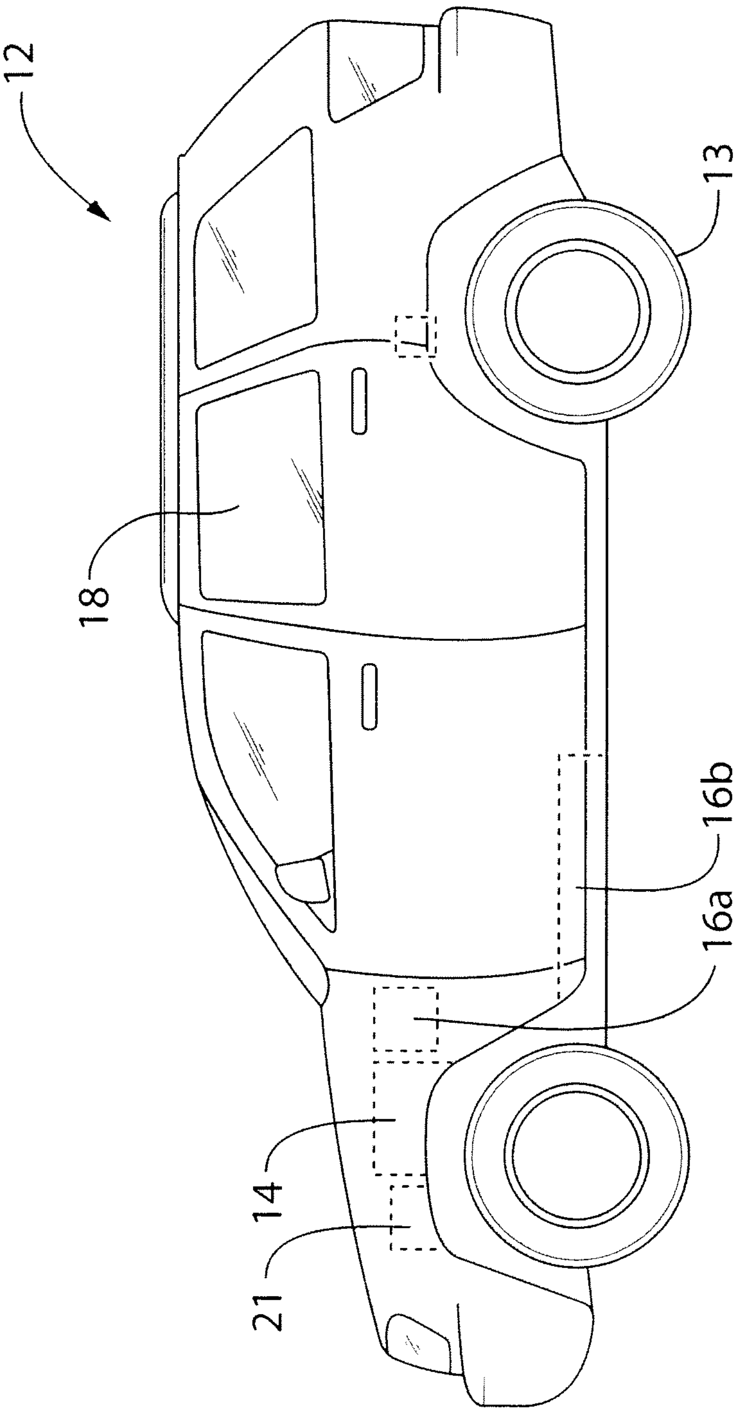

FIG. 1

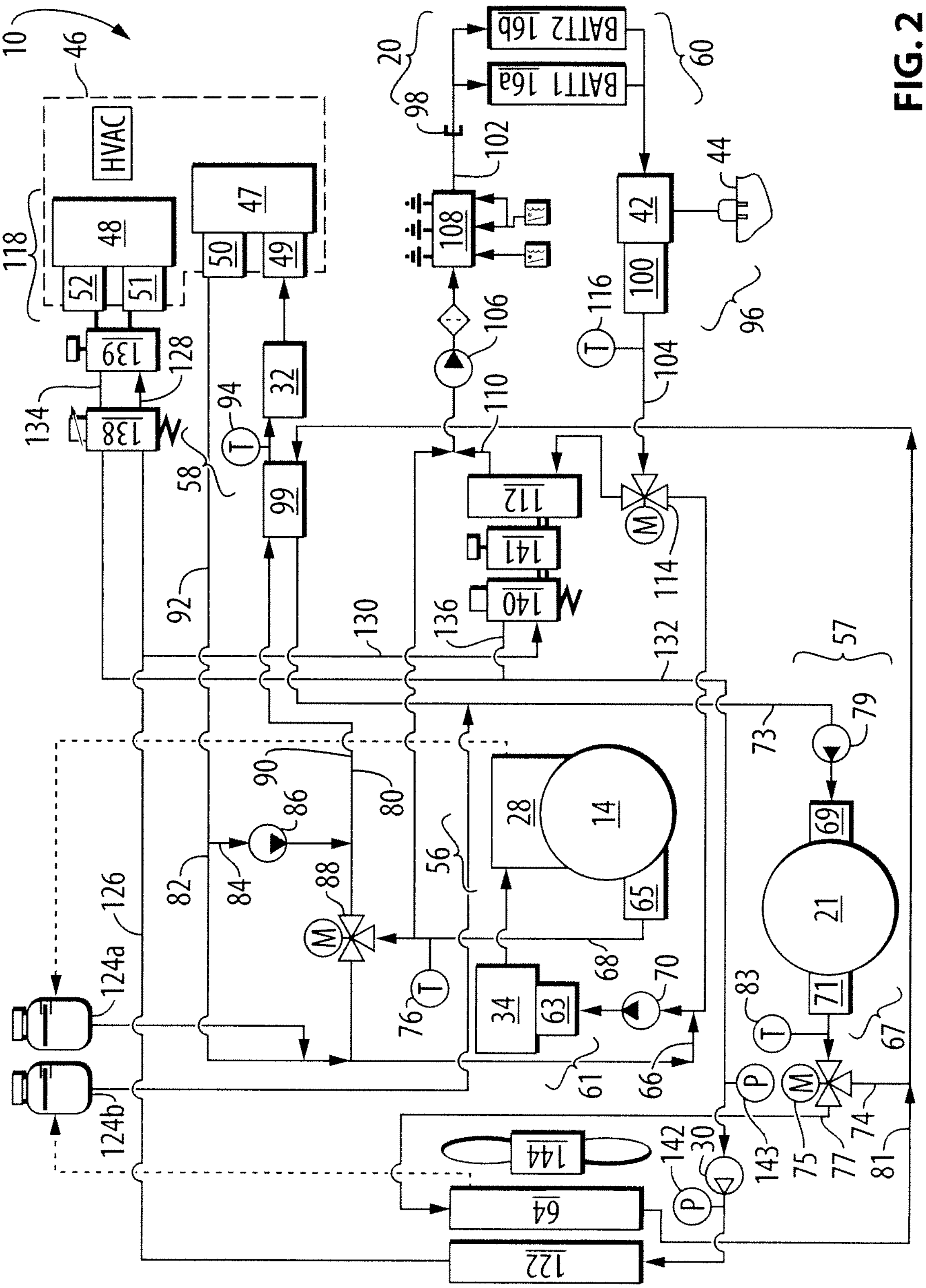

FIG. 2

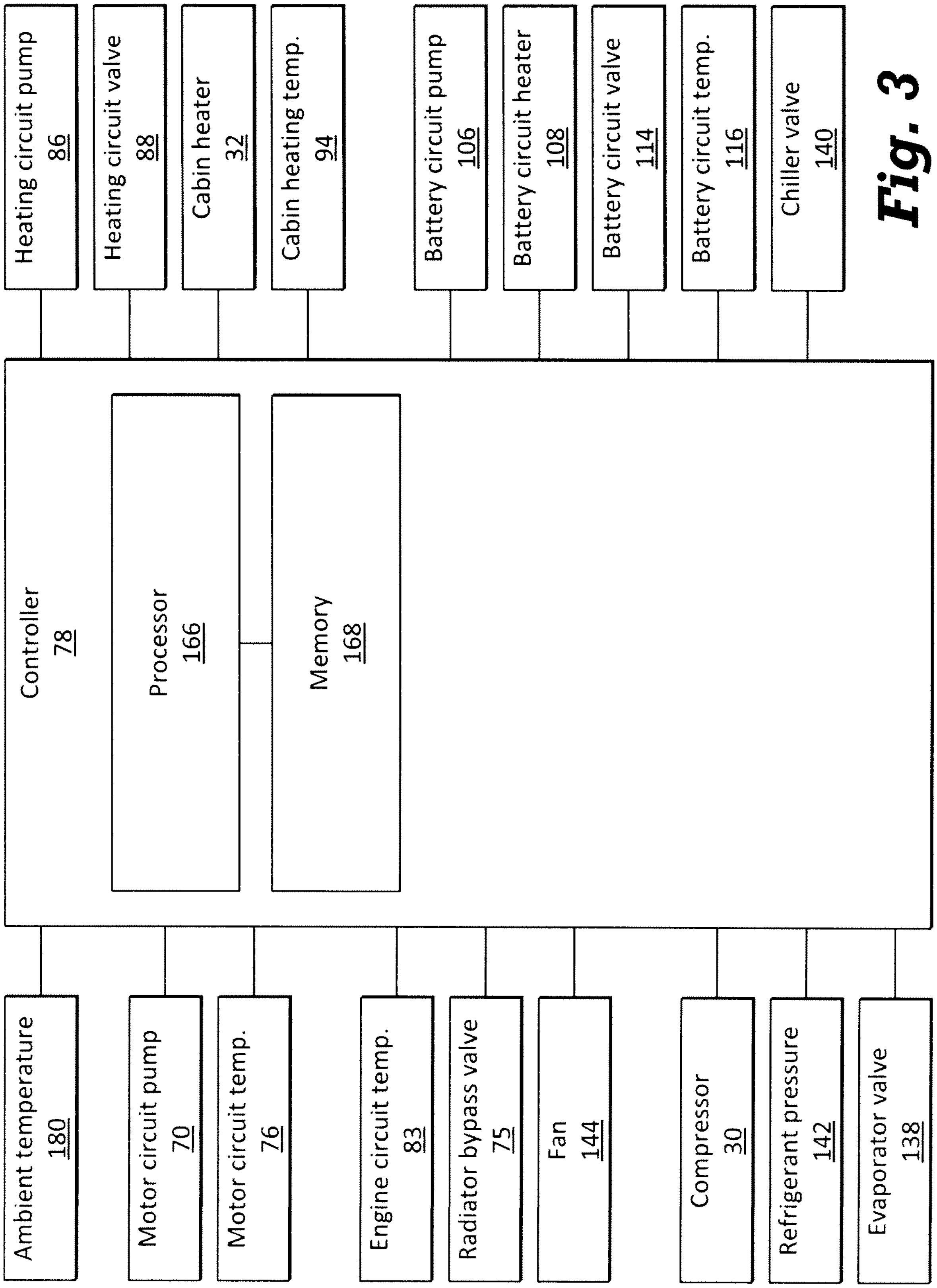
Heating circuit pump 86
Heating circuit valve 88
Cabin heater 32
Cabin heating temp. 94
Battery circuit pump 106
Battery circuit heater 108
Battery circuit valve 114
Battery circuit temp. 116
Chiller valve 140
Controller 78
Processor 166
Memory 168
Ambient temperature 180
Motor circuit pump 70
Motor circuit temp. 76
Engine circuit temp. 83
Radiator bypass valve 75
Fan 144
Compressor 30
Refrigerant pressure 142
Evaporator valve 138

Fig. 3

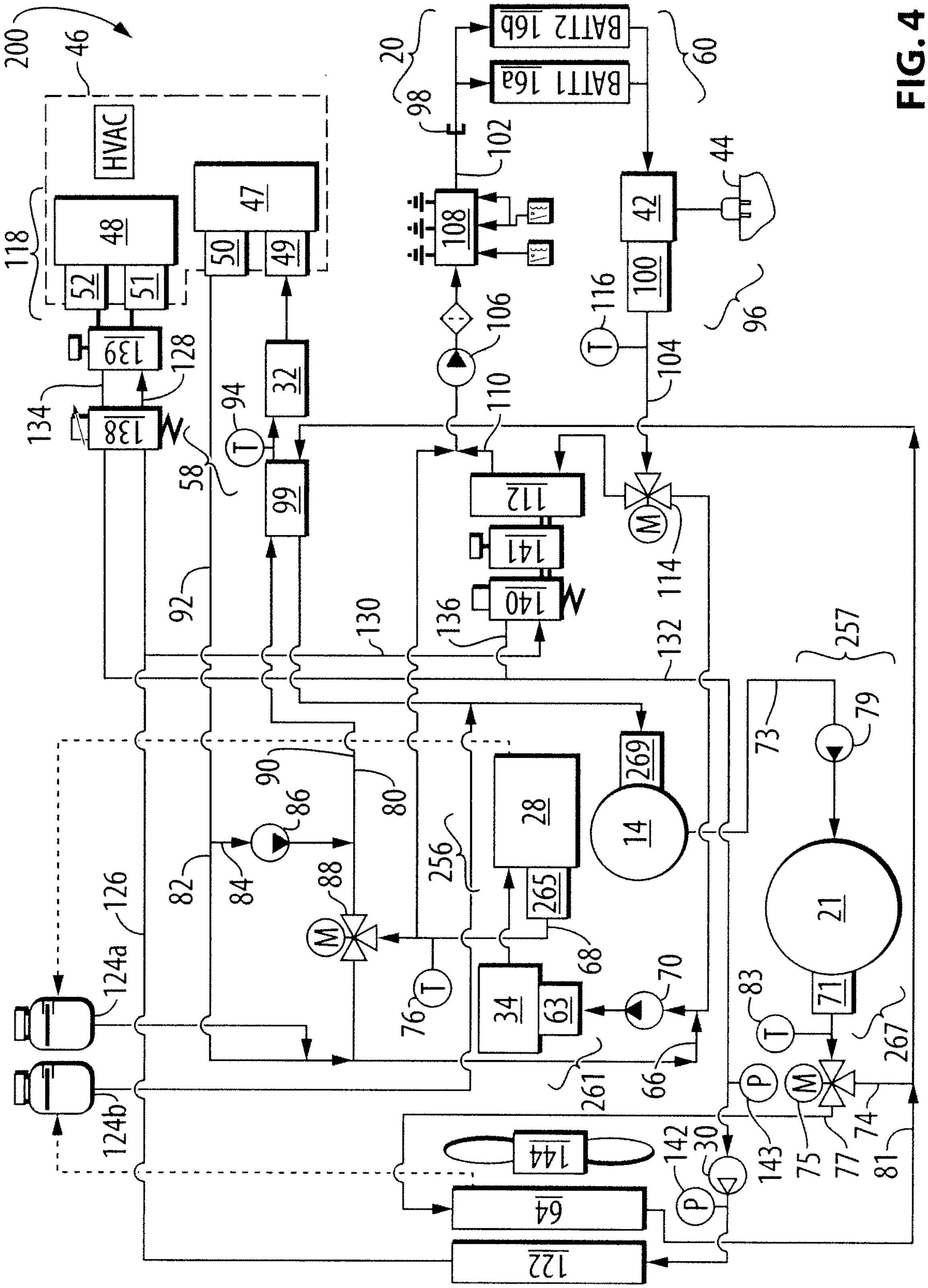
200
46
HVAC
118
48
52
51
47
50
49
20
98
102
BATT1 16a
BATT2 16b
60
108
106
42
44
100
116
T
96
104
139
128
134
138
58
94
32
99
92
110
112
141
140
114
M
130
136
132
257
73
79
126
82
84
86
90
80
88
256
28
14
269
265
68
21
124a
124b
76
34
63
70
261
66
83
71
267
P
143
75
77
74
81
142
30
144
64
122

FIG. 4

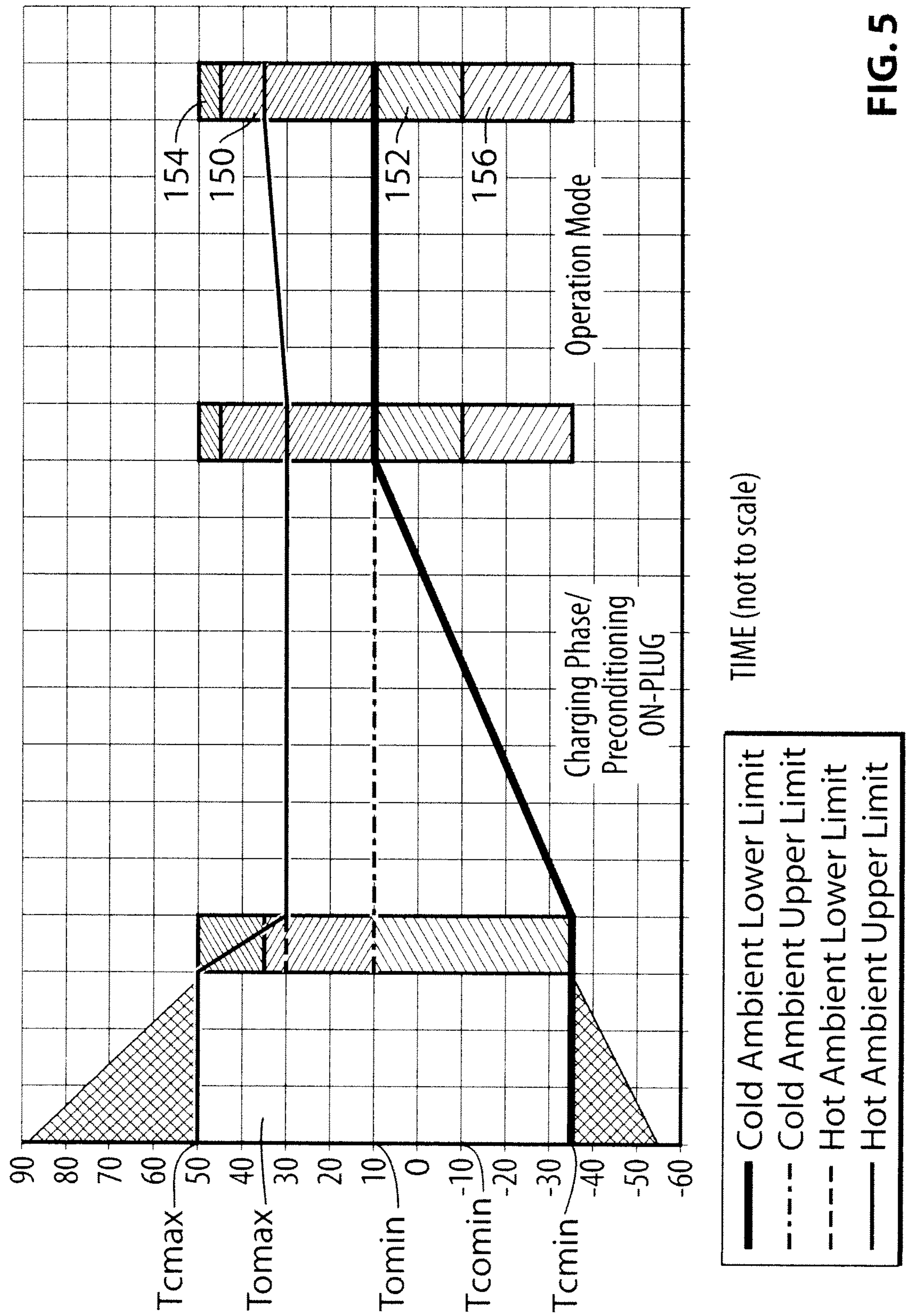
Tcmax
Tomax
Tomin
Tcomin
Tcmin
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
154
150
152
156
Operation Mode
Charging Phase/
Preconditioning
ON-PLUG
TIME (not to scale)
Cold Ambient Lower Limit
Cold Ambient Upper Limit
Hot Ambient Lower Limit
Hot Ambient Upper Limit

FIG. 5

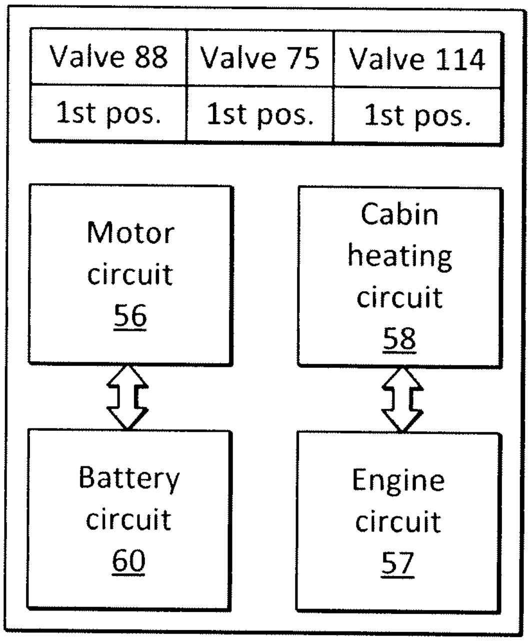

Fig. 6a

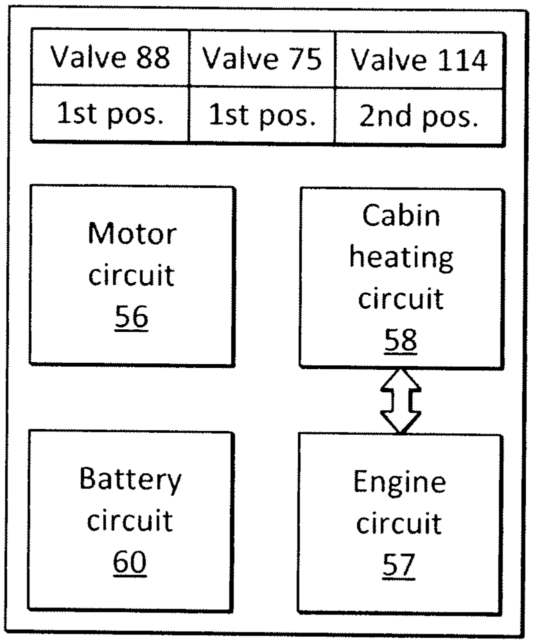

Fig. 6b

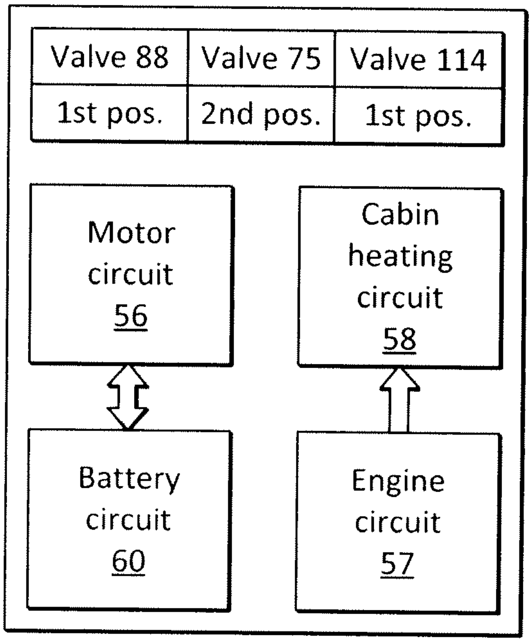

Fig. 6c

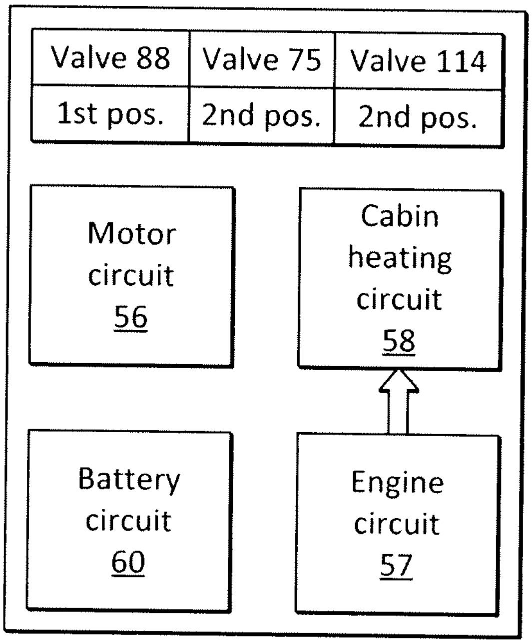

Fig. 6d

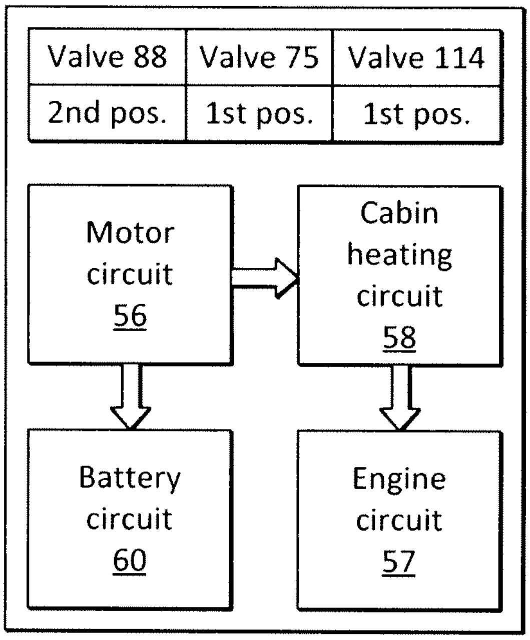

Fig. 6e

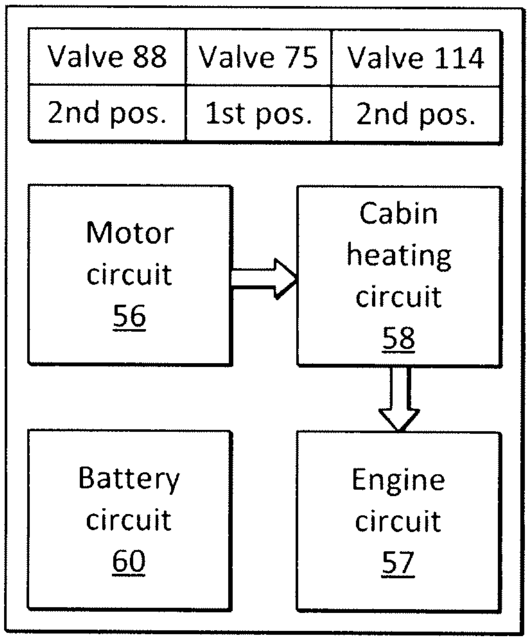

Fig. 6f

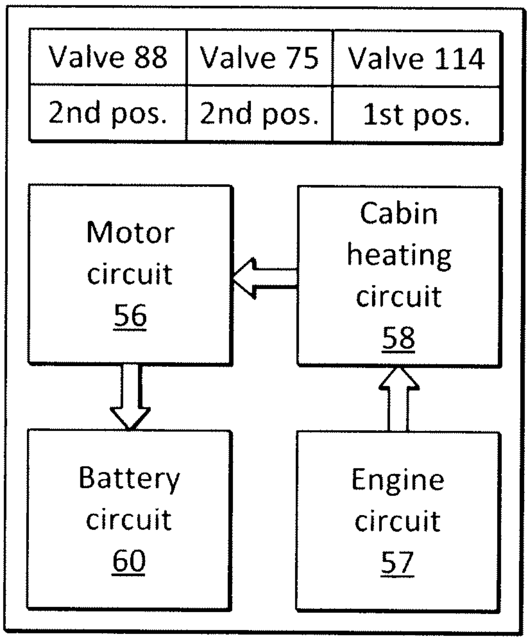

Fig. 6g

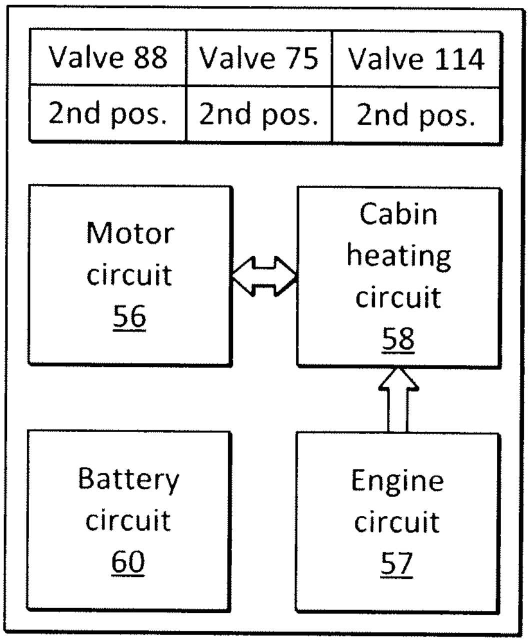

Fig. 6h

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/035721

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60H1/00 B60H1/14 B60H1/03
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B60H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 198 50 829 C1 (VALEO KLIMASYSTEME GMBH [DE]) 16 March 2000 (2000-03-16) columns 3-7; figure 1	1-16
A	FR 2 951 114 A1 (PEUGEOT CITROEN AUTOMOBILES SA [FR]) 15 April 2011 (2011-04-15) pages 1-8; figure 2	1-16
A	WO 93/02884 A1 (TECHNOLOGY PARTNERSHIP [GB]) 18 February 1993 (1993-02-18) claims; figure 1	1-16
X	EP 1 637 709 A2 (BEHR GMBH & CO [DE] BEHR GMBH & CO KG [DE]) 22 March 2006 (2006-03-22) claims; figure 1	17-19

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 June 2013	05/07/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Chavel, Jérôme

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/035721

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2004/092662 A1 (TOYOTA MOTOR CO LTD [JP]; INAOKA HIROYA [JP]) 28 October 2004 (2004-10-28) the whole document -----	1-19
A	DE 197 30 678 A1 (VOLKSWAGEN AG [DE]) 21 January 1999 (1999-01-21) the whole document -----	1-19

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/035721

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
DE 19850829	C1	16-03-2000	DE	19850829 C1	16-03-2000
			EP	0999078 A1	10-05-2000
			ES	2215355 T3	01-10-2004
			JP	2000264045 A	26-09-2000
			US	2004000161 A1	01-01-2004
FR 2951114	A1	15-04-2011	CN	102575567 A	11-07-2012
			EP	2488737 A1	22-08-2012
			FR	2951114 A1	15-04-2011
			US	2012199313 A1	09-08-2012
			WO	2011045496 A1	21-04-2011
WO 9302884	A1	18-02-1993	AT	133376 T	15-02-1996
			AU	667679 B2	04-04-1996
			CA	2114834 A1	18-02-1993
			DE	69207909 D1	07-03-1996
			DE	69207909 T2	30-05-1996
			DK	0596000 T3	10-06-1996
			EP	0596000 A1	11-05-1994
			ES	2085637 T3	01-06-1996
			GR	3019096 T3	31-05-1996
			JP	H09507444 A	29-07-1997
			US	5531285 A	02-07-1996
			WO	9302884 A1	18-02-1993
EP 1637709	A2	22-03-2006	EP	1637709 A2	22-03-2006
			JP	4891584 B2	07-03-2012
			JP	2006082805 A	30-03-2006
			US	2006060340 A1	23-03-2006
WO 2004092662	A1	28-10-2004	CN	1701209 A	23-11-2005
			DE	602004006248 T2	27-12-2007
			EP	1613903 A1	11-01-2006
			JP	4321587 B2	26-08-2009
			JP	2006523813 A	19-10-2006
			US	2005247336 A1	10-11-2005
			WO	2004092662 A1	28-10-2004
DE 19730678	A1	21-01-1999	NONE		