US 20140338376A1

(19) **United States**

(12) **Patent Application Publication**

Carpenter et al.

(10) **Pub. No.: US 2014/0338376 A1**

(43) **Pub. Date: Nov. 20, 2014**

(54) **THERMAL MANAGEMENT SYSTEM FOR VEHICLE HAVING TRACTION MOTOR**

(71) Applicant: **Magna E-Car System of America, Inc.**, Auburn Hills, MI (US)

(72) Inventors: **Neil Carpenter**, Clarkston, MI (US); **Guanging Gao**, Rochester Hills, MI (US)

(21) Appl. No.: **14/368,977**

(22) PCT Filed: **Dec. 17, 2012**

(86) PCT No.: **PCT/US12/70084**

§ 371 (c)(1),
(2), (4) Date: **Jun. 26, 2014**

Related U.S. Application Data

(60) Provisional application No. 61/581,466, filed on Dec. 29, 2011.

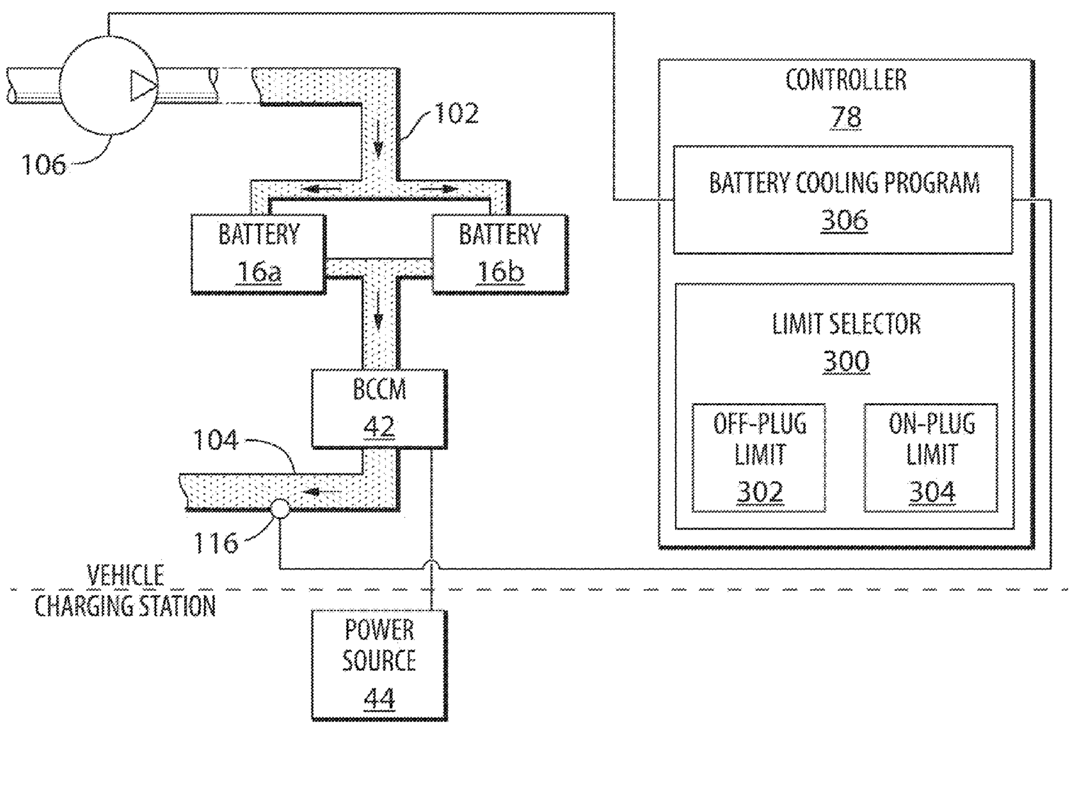
Publication Classification

(51) **Int. Cl.**
B60H 1/00 (2006.01)

(52) **U.S. Cl.**
CPC ***B60H 1/00392*** (2013.01); ***B60H 1/00278*** (2013.01); *B60H 2001/00307* (2013.01); *B60H 2001/00942* (2013.01)
USPC **62/115**; 62/228.1

(57) **ABSTRACT**

A thermal management system for a vehicle includes a traction motor and a battery pack. The thermal management system comprises a battery circuit for cooling a battery circuit thermal load including the battery pack, a battery circuit temperature sensor positioned to sense a temperature relating to a temperature of the battery circuit thermal load, and a controller. The controller is configured to control the battery circuit to maintain the temperature sensed by the battery circuit temperature sensor below a first battery circuit temperature limit when the controller detects that the vehicle is not connected to an external electrical source, and to maintain the temperature sensed by the battery circuit temperature sensor below a second battery circuit temperature limit that is lower than the first battery circuit temperature limit when the controller detects that the vehicle is connected to the external electrical source.



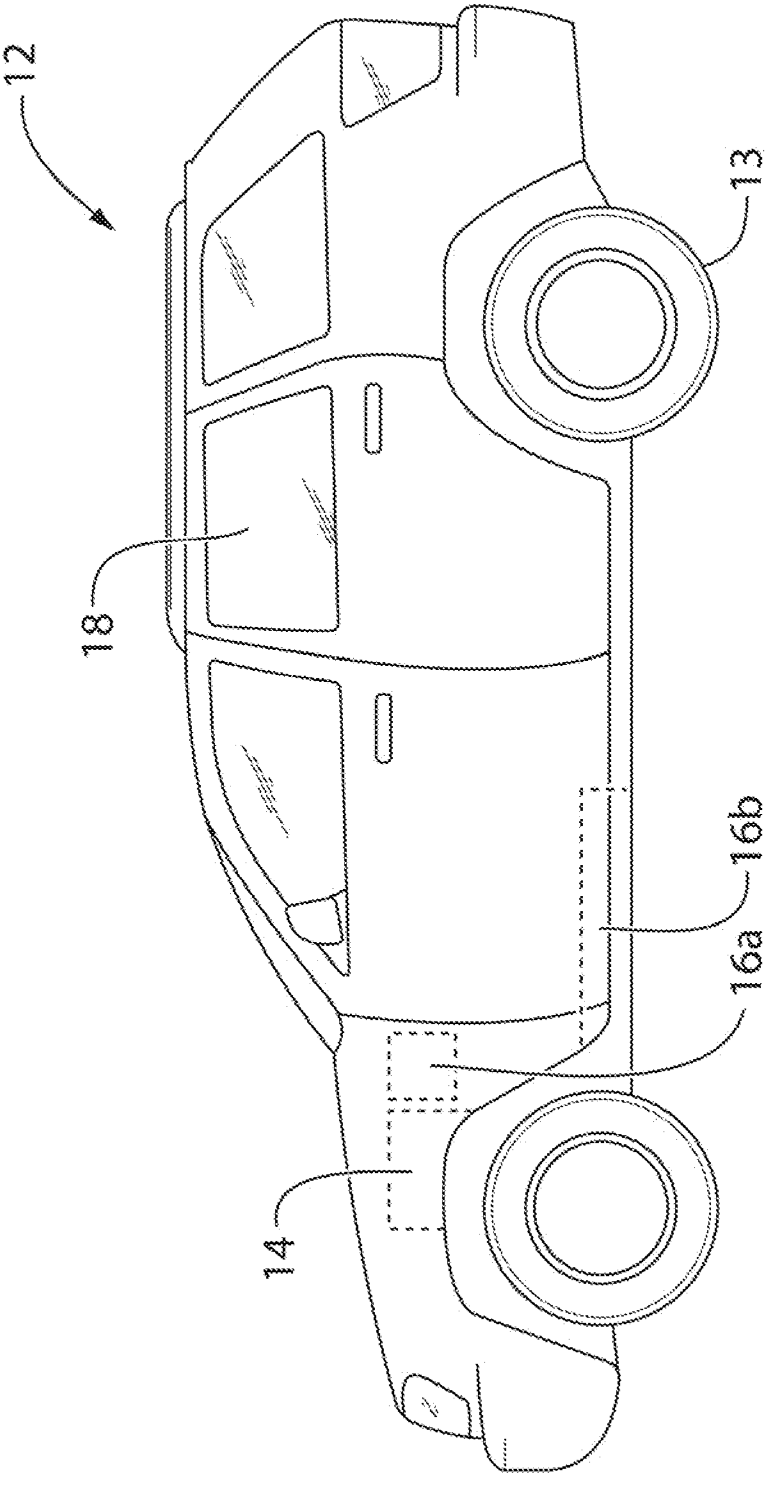


FIG. 1

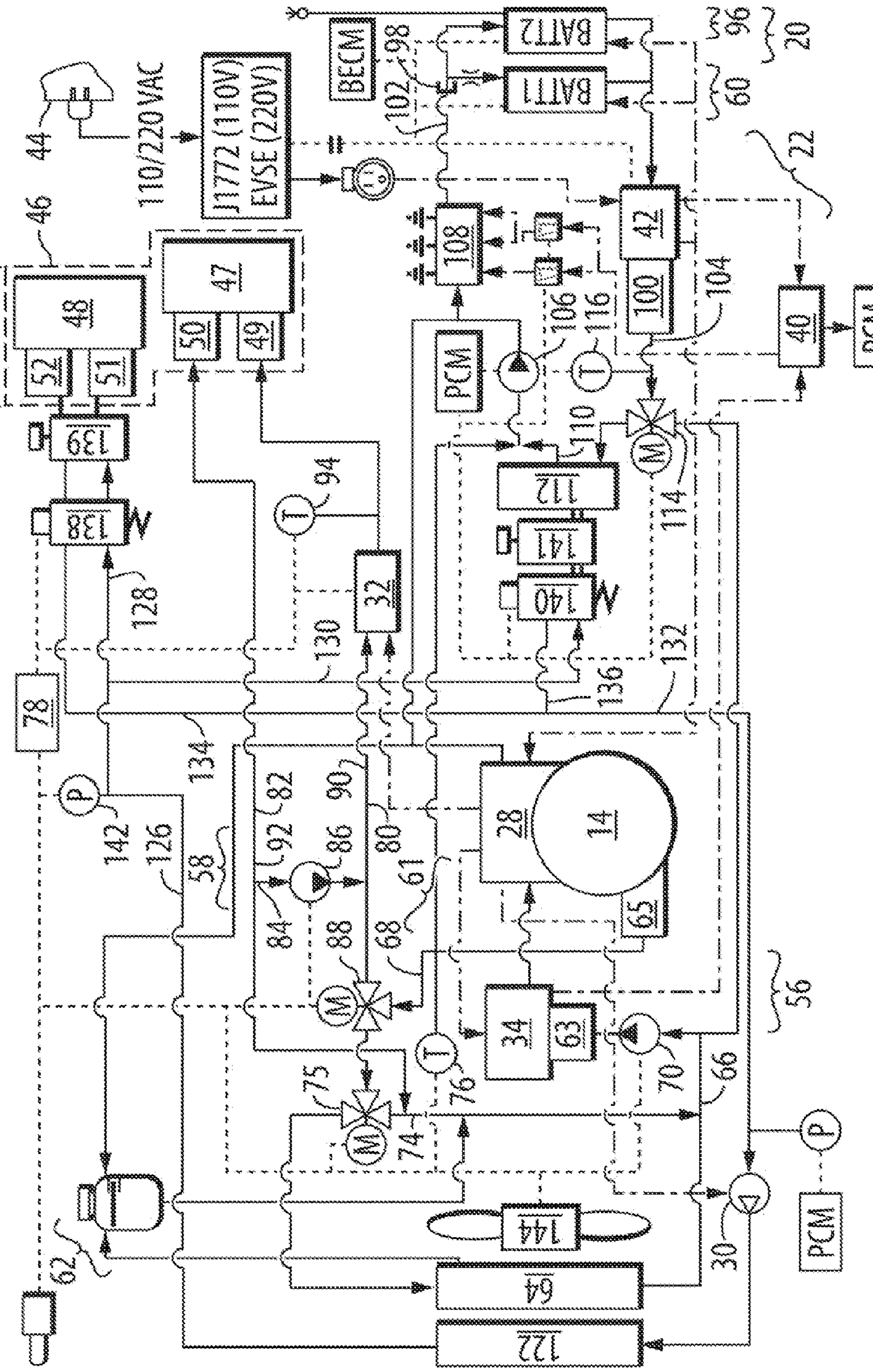

110/220 VAC
J1772 (110V)
EVSE (220V)
BECM
BATT1
BATT2
PCM
PCM
PCM
PCM

FIG. 2

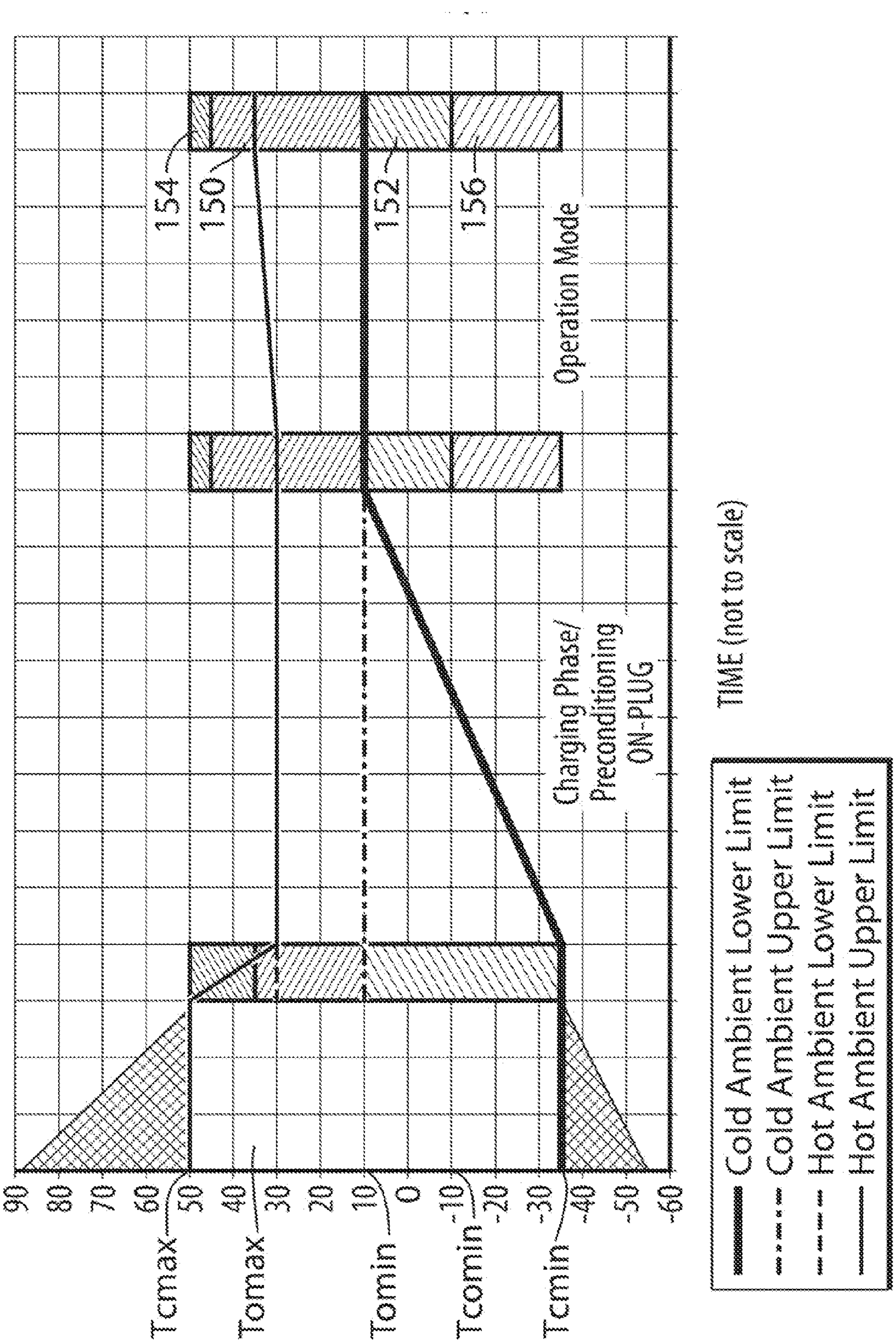

90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Tcmax
Tomax
Tomin
Tcomin
Tcmin
154
150
152
156
Operation Mode
Charging Phase/
Preconditioning
ON-PLUG
TIME (not to scale)
Cold Ambient Lower Limit
Cold Ambient Upper Limit
Hot Ambient Lower Limit
Hot Ambient Upper Limit

FIG.3

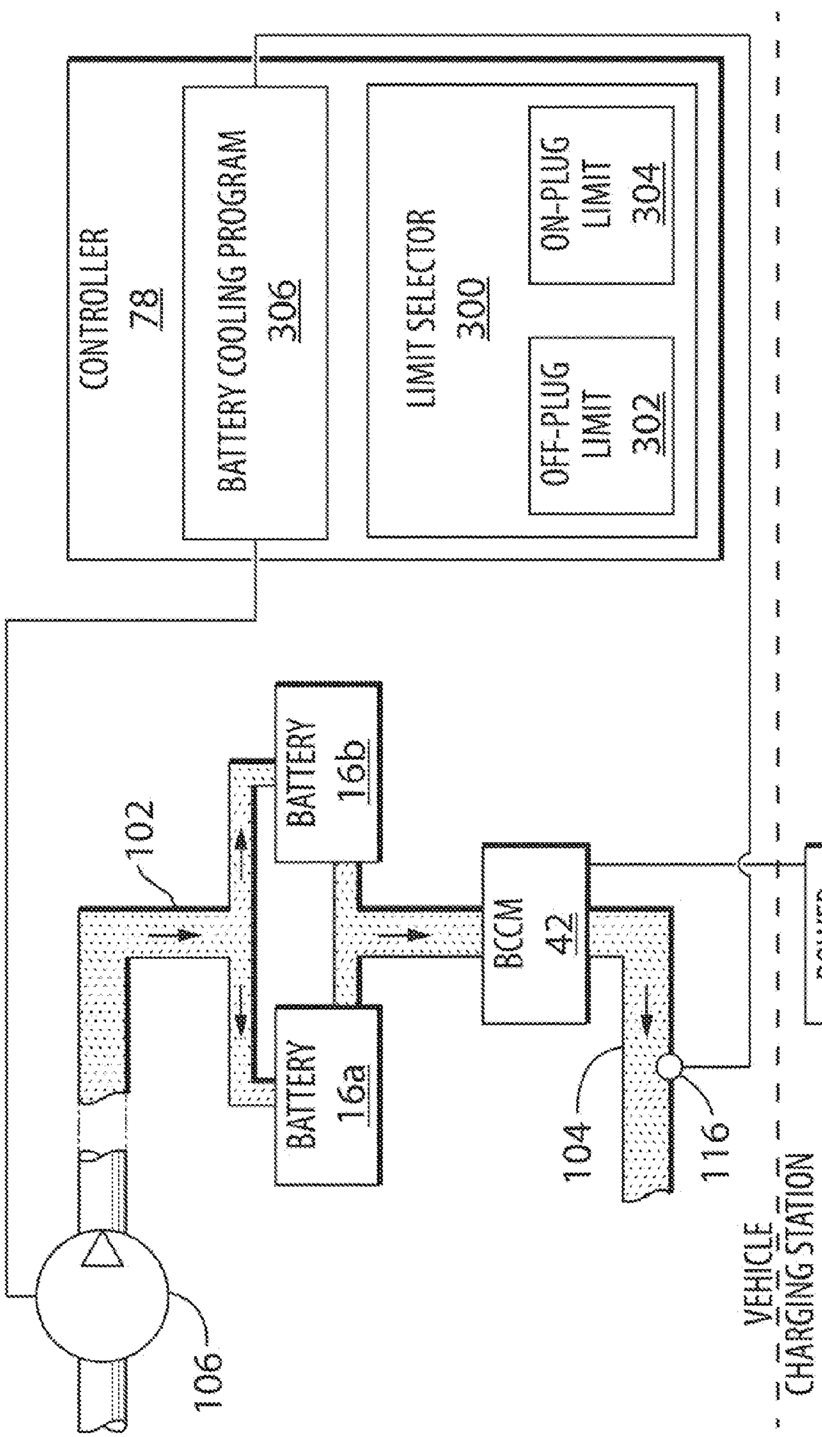

CONTROLLER
78
BATTERY COOLING PROGRAM
306
LIMIT SELECTOR
300
OFF-PLUG
LIMIT
302
ON-PLUG
LIMIT
304
102
BATTERY
16b
BATTERY
16a
BCCM
42
POWER
SOURCE
44
104
116
106
VEHICLE
CHARGING STATION

FIG.4

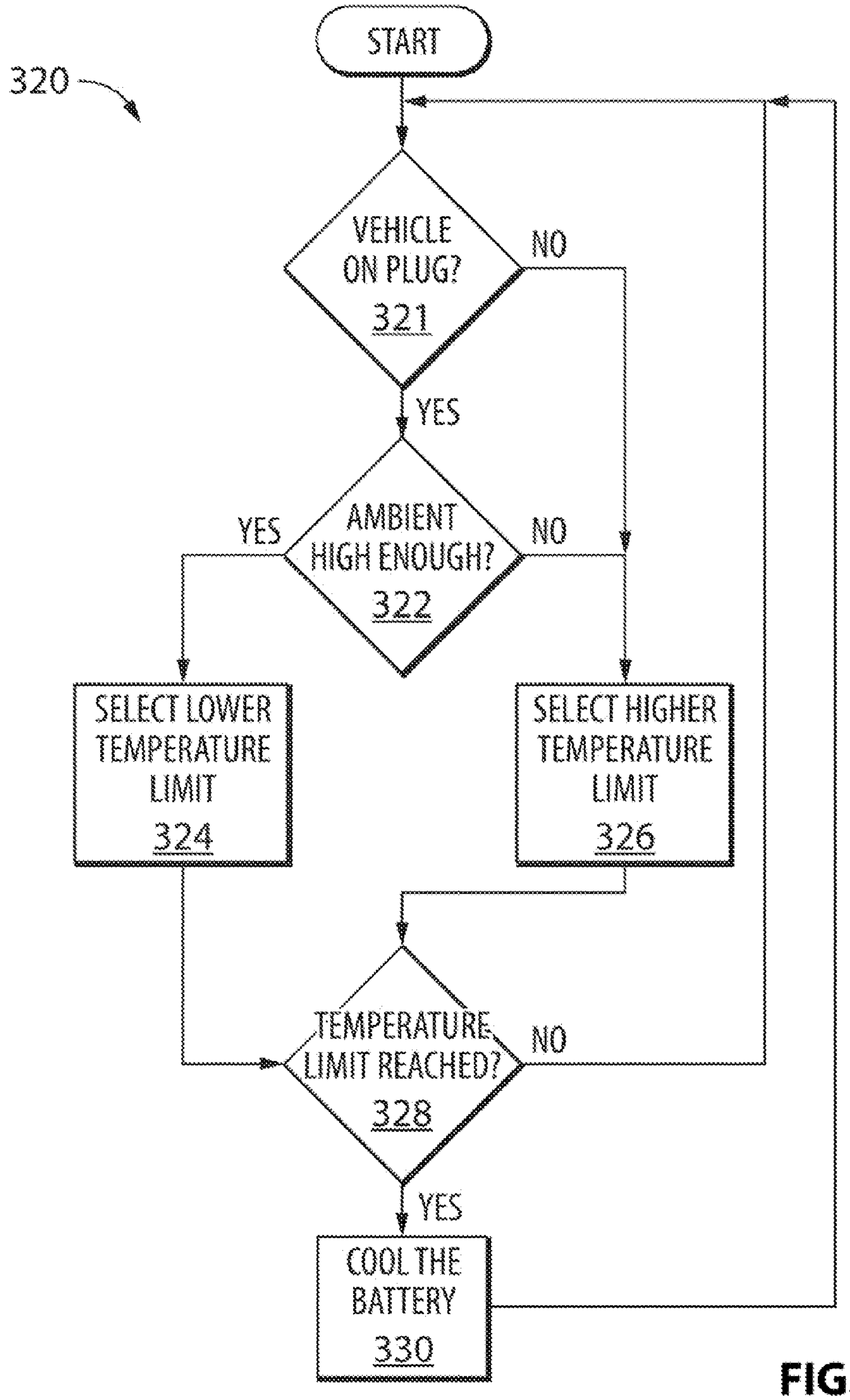

320
START
VEHICLE ON PLUG?
321
NO
YES
AMBIENT HIGH ENOUGH?
322
YES
NO
SELECT LOWER TEMPERATURE LIMIT
324
SELECT HIGHER TEMPERATURE LIMIT
326
TEMPERATURE LIMIT REACHED?
328
NO
YES
COOL THE BATTERY
330

FIG.5

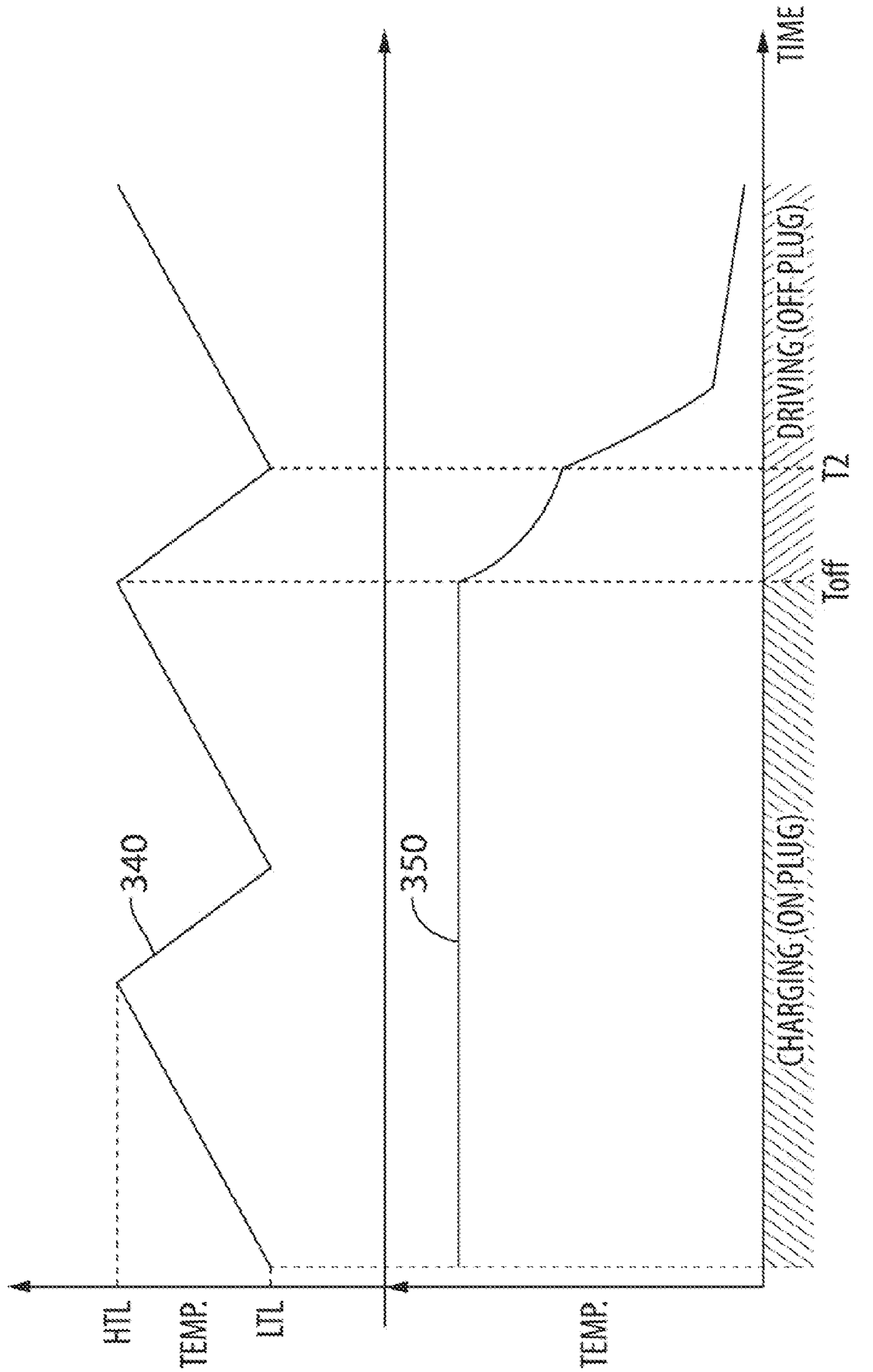

HTL
TEMP.
LTL
340
350
TEMP.
TIME
CHARGING (ON PLUG)
DRIVING (OFF PLUG)
Toff
T2

FIG.6

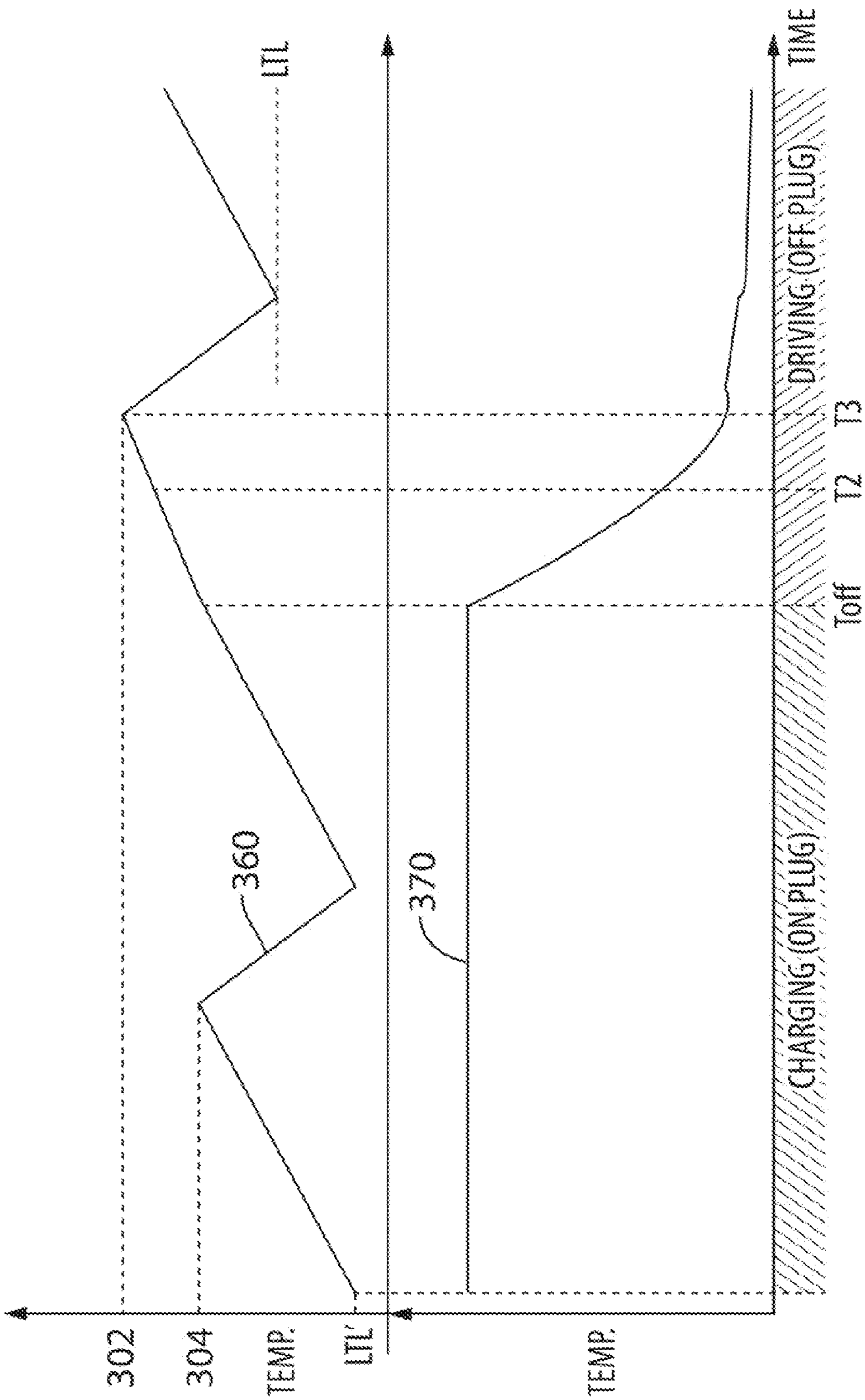

302
304
TEMP.
LTL'
TEMP.
360
370
LTL
TIME
CHARGING (ON PLUG)
DRIVING (OFF PLUG)
Toff
T2
T3

FIG.7

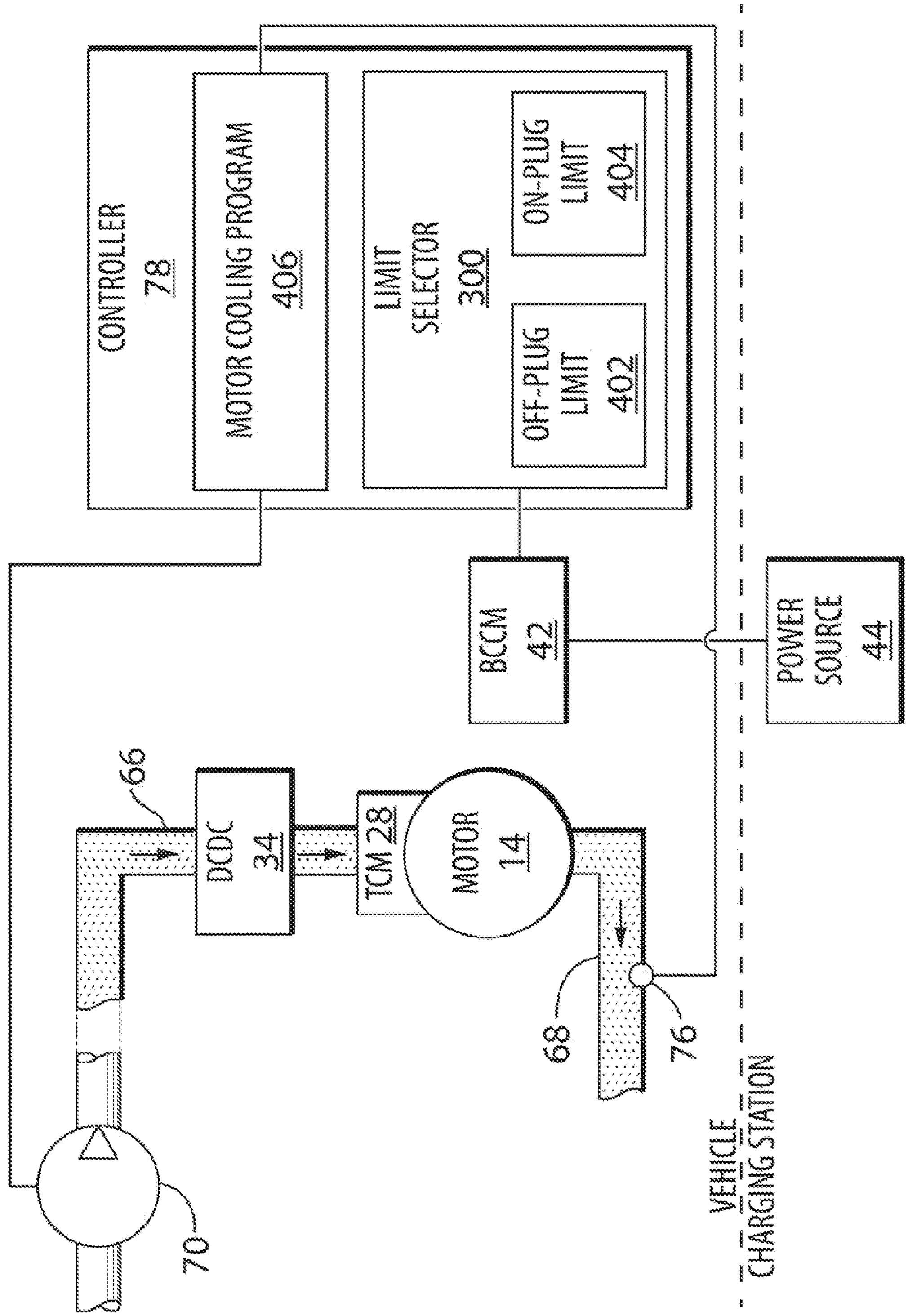

CONTROLLER
78
MOTOR COOLING PROGRAM
406
LIMIT
SELECTOR
300
OFF-PLUG
LIMIT
402
ON-PLUG
LIMIT
404
BCCM
42
POWER
SOURCE
44
66
DCDC
34
TCM 28
MOTOR
14
68
76
70
VEHICLE
CHARGING STATION

FIG.8

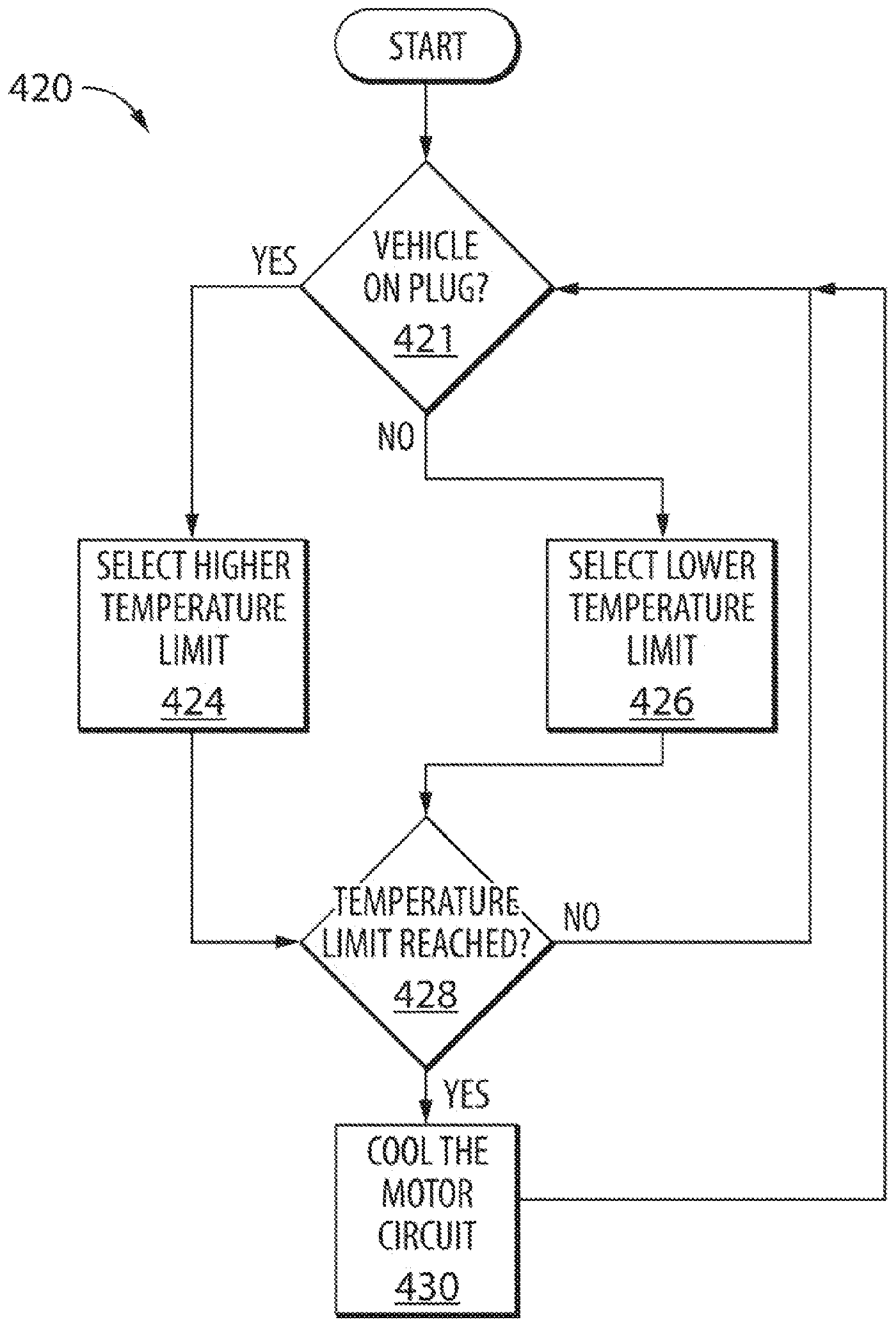

420
START
VEHICLE ON PLUG?
421
YES
NO
SELECT HIGHER TEMPERATURE LIMIT
424
SELECT LOWER TEMPERATURE LIMIT
426
TEMPERATURE LIMIT REACHED?
428
NO
YES
COOL THE MOTOR CIRCUIT
430

FIG.9

THERMAL MANAGEMENT SYSTEM FOR VEHICLE HAVING TRACTION MOTOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a U.S. National Stage of International Application No. PCT/US2012/070084 filed Dec. 17, 2012 which claims priority to and the benefit of U.S. Provisional Application No. 61/581,466 filed Dec. 29, 2011. The entire disclosure of each of the above-noted applications is hereby incorporated by reference.

FIELD

[0002] The present disclosure relates to vehicles that are powered at least partly by an electric motor and more particularly to battery electric vehicles with no internal combustion engine on board.

BACKGROUND

[0003] This section provides background information related to the present disclosure which is not necessarily prior art.

[0004] Vehicles with traction motors offer the promise of powered transportation while producing few or no emissions at the vehicle. Such vehicles may be referred to as electric vehicles, however it will be noted that some electric vehicles include only an electric motor, while some electric vehicles include both a traction motor and an internal combustion engine. For example, some electric vehicles are powered by electric motors only and rely solely on the energy stored in an on-board battery pack. Some electric 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.

[0005] While currently proposed and existing vehicles are advantageous in some respects over internal-combustion engine powered vehicles, there are problems that are associated with some such vehicles. A particular problem is that their range is typically relatively short as compared to internal combustion engine-powered vehicles. This is particularly true for battery electric vehicles since they are not equipped with range extender engines. A reason for their typically relatively short range is the weight and cost of the battery packs used to store energy for the operation of such vehicles. It would be beneficial to provide technology that improves the efficiency with which power is used in the operation of the vehicle, so as to improve the range of such vehicles.

SUMMARY

[0006] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope of all of its features.

[0007] According to one aspect of this disclosure, a thermal management system for a vehicle is disclosed. The vehicle includes a traction motor and a battery pack. The thermal management system comprises a battery circuit for cooling a battery circuit thermal load including the battery pack, a battery circuit temperature sensor positioned to sense a temperature relating to a temperature of the battery circuit thermal load, and a controller. The controller is configured to control the battery circuit to maintain the temperature sensed by the battery circuit temperature sensor below a first battery circuit temperature limit when the controller detects that the vehicle is not connected to an external electrical source, and to maintain the temperature sensed by the battery circuit temperature sensor below a second battery circuit temperature limit that is lower than the first battery circuit temperature limit when the controller detects that the vehicle is connected to the external electrical source.

[0008] The system may further include a battery charge control module that controls electrical current sent to the battery pack from the external electrical source. The battery charge control module makes up part of the battery circuit thermal load.

[0009] The vehicle may further include a passenger cabin. The system may further include a first heat exchanger positioned to cool fluid in the battery circuit, a second heat exchanger positioned to cool an airflow leading to the passenger cabin, a compressor, positioned to compress refrigerant and to send the refrigerant through a refrigerant circuit leading to the first and second heat exchangers.

[0010] The first and second heat exchangers may be a chiller and an evaporator respectively.

[0011] The battery circuit can further include a valve positioned to connect the battery circuit to a motor circuit that includes a radiator.

[0012] The second temperature limit can be lower than the first temperature limit by between about 1 and about 3 degrees Celsius.

[0013] The thermal management system can further include a motor circuit for cooling a motor circuit thermal load including the traction motor, the motor circuit including a motor circuit pump. The thermal management system can further include a motor circuit temperature sensor positioned to sense a temperature of fluid in the motor circuit. The controller can be further configured to control the motor circuit to maintain the temperature sensed by the motor circuit temperature sensor below a first motor circuit temperature limit when detecting that the battery charge control module is not connected to the electrical source, and to control the motor circuit to maintain the temperature sensed by the motor circuit temperature sensor below a second motor circuit temperature limit that is higher than the third temperature limit when detecting that the battery charge control module is connected to the electrical source.

[0014] According to another aspect of this disclosure, an electric vehicle can include a passenger cabin, wheels coupled to the passenger cabin, a traction motor coupled to the wheels and configured to drive the wheels, a battery pack coupled to the traction motor and configured to provide electricity to the traction motor, and the thermal management system described above.

[0015] According to another aspect of this disclosure, a thermal management system for a vehicle is disclosed. The vehicle includes a traction motor, a battery, a battery charge control module, and a passenger cabin. The thermal management system includes a motor circuit for cooling a motor circuit thermal load including the traction motor, a motor circuit temperature sensor positioned to sense a temperature of fluid in the motor circuit, and a controller. The controller is configured to control the motor circuit to maintain the temperature sensed by the motor circuit temperature sensor below a first motor circuit temperature limit when the controller detects that the vehicle is not connected to an external electrical source, and to maintain the temperature sensed by the motor circuit temperature sensor below a second motor circuit temperature limit that is higher than the first motor circuit temperature limit when the controller detects that the vehicle is connected to an external electrical source.

[0016] According to a still further aspect of this disclosure, a method is provided of cooling a battery circuit thermal load for a battery circuit of a vehicle. The vehicle includes a traction motor and a battery pack that is at least part of the battery circuit thermal load. The method include the steps of cooling the battery circuit thermal load to maintain a temperature of the battery circuit thermal load below a first battery circuit temperature limit while not charging the battery pack using an external electrical source, and cooling the battery circuit thermal load to maintain the temperature of the battery circuit thermal load below a second battery circuit temperature limit, the second battery circuit temperature limit being lower than the first battery circuit temperature limit while charging the battery pack using an external electrical source.

[0017] In an embodiment, the vehicle includes a passenger cabin, a first heat exchanger positioned to cool fluid in the battery circuit, a second heat exchanger positioned to cool an airflow leading to the passenger cabin, and a compressor, positioned to compress refrigerant and to send the refrigerant through a refrigerant circuit leading to the first and second heat exchangers.

[0018] The first and second temperature limits can be selected based on performance of an evaporator of the electric vehicle.

[0019] The method can further include determining an ambient temperature to be above a threshold as a condition for cooling the battery to maintain the temperature of the battery below the second temperature limit.

[0020] The method can further include cooling a battery charge control module when cooling the battery.

[0021] The second temperature limit can be lower than the first temperature limit by between about 1 and about 3 degrees Celsius.

[0022] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

[0024] The present disclosure will now be described, by way of example only, with reference to the attached drawings, in which:

[0025] FIG. **1** is a perspective view of an electric vehicle that includes a thermal management system in accordance with an embodiment of the present disclosure;

[0026] FIG. **2** is a schematic illustration of a thermal management system for the electric vehicle;

[0027] FIG. **3** is a graph of the temperature of battery packs that are part of the electric vehicle shown in FIG. **1**;

[0028] FIG. **4** is a block diagram of a portion of the thermal management system showing components of the controller for cooling a battery using two temperature limits;

[0029] FIG. **5** is a flowchart of a method of cooling the battery using two temperature limits;

[0030] FIG. **6** is a chart showing battery and evaporator temperatures when charging and when driving;

[0031] FIG. **7** is a chart showing battery and evaporator temperatures when charging and when driving according to two temperature limits for the battery;

[0032] FIG. **8** is a block diagram of a portion of the thermal management system showing components of the controller for cooling the motor circuit using two temperature limits; and

[0033] FIG. **9** is a flowchart of a method of cooling the motor circuit using two temperature limits.

DETAILED DESCRIPTION

[0034] Example embodiments will now be described more fully with reference to the accompanying drawings. However, the example embodiments are only provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0035] Reference is made to FIG. **2**, which shows a schematic illustration of a thermal management system **10** for an electric vehicle **12** shown in FIG. **1**. The electric vehicle **12** includes wheels **13**, a traction motor **14** for driving the wheels **13**, first and second battery packs **16***a* and **16***b*, a cabin **18**, a high voltage electrical system **20** (FIG. **2**) and a low voltage electrical system **22** (FIG. **2**).

[0036] The motor **14** may have any suitable configuration for use in powering the electric vehicle **12**. The motor **14** may be mounted in a motor compartment that is forward of the cabin **18** and that is generally in the same place an engine compartment is on a typical internal combustion powered vehicle. Referring to FIG. **2**, the motor **14** generates heat during use and thus requires cooling. To this end, the motor **14** includes a motor coolant flow conduit for transporting coolant fluid about the motor **14** so as to maintain the motor within a suitable temperature range.

[0037] A transmission control system 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 system **28** generates heat during use and thus has a transmission control system coolant flow conduit associated therewith, for transporting coolant fluid about the transmission control system **28** so as to maintain the transmission control system **28** within a suitable temperature range. The transmission control system **28** may be positioned immediately upstream fluidically from the motor **14**.

[0038] The DC/DC converter **34** receives current from the transmission control system **28** and converts the current from high voltage to low voltage. The DC/DC converter **34** sends the low voltage current to a low voltage battery shown at **40**, which is used to power low voltage loads in the vehicle **12**. The low voltage battery **40** may operate on any suitable voltage, such as 12 V.

[0039] The battery packs **16***a* and **16***b* send power to the transmission control system **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 **16***a* and **16***b* may be any suitable types of battery packs. In an embodiment, the battery packs **16***a* and **16***b* are each made up of a plurality of lithium polymer cells. The battery packs **16***a* and **16***b* have a temperature range (shown in FIG. **3**) in which the battery packs **16***a* and **16***b* may be maintained so as to provide a relatively long operating life. While two battery packs **16***a* and **16***b* 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**.

[0040] A battery charge control module shown at **42** is provided and is configured to connect the vehicle **12** to an electrical source (eg. a 110V source, or a 220V 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 **16***a* and **16***b*, the transmission control system **28** and the low voltage battery **40**. 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** from a battery charge control module inlet **4** to a battery charge control module outlet **26** so as to maintain the battery charge control module **42** within a suitable temperature range.

[0041] An HVAC system **46** is provided for controlling the temperature of the cabin **18** (FIG. **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 cabin heating heat exchanger **47** and a 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**.

[0042] The motor **14**, the transmission control system **28**, the DC/DC converter **34**, the battery packs **16***a* and **16***b*, the battery charge control module **42** and the HVAC system **46** constitute thermal loads on the thermal management system **10**.

[0043] The thermal management system **10** includes a motor circuit **56**, a cabin heating circuit **58**, a battery circuit **60** and a main cooling circuit **62**. The motor circuit **56** is configured for cooling the traction motor **14**, the transmission control system **28** and the DC/DC converter **34**, which constitute a motor circuit thermal load **61**, which has a motor circuit thermal load inlet **63** and a motor circuit thermal load outlet **65**. The motor circuit **56** includes a radiator **64**, a first motor circuit conduit **66** fluidically between the radiator **64** to the motor circuit thermal load inlet **63**, a second motor circuit conduit **68** fluidically between the motor circuit thermal load outlet **65** and the radiator **64**, and a motor circuit pump **70** positioned to pump heat exchange fluid through the motor circuit **56**.

[0044] Additionally a third motor circuit conduit **74** may be provided fluidically between the second and first motor circuit conduits **68** and **66** so as to permit the flow of heat exchange fluid to bypass the radiator **64** when possible (eg. when the heat exchange fluid is below a selected threshold temperature). To control whether the flow of heat exchange fluid is directed through the radiator **64** or through the third motor circuit conduit **74**, a radiator bypass valve **75** is provided and may be positioned in the second motor circuit conduit **68**. The radiator bypass valve **75** is controllable so that in a first position the valve **75** directs the flow of heat exchange fluid to the radiator **64** through the second motor circuit conduit **68** and in a second position the valve **75** directs the flow of heat exchange fluid to the first motor circuit conduit **66** through the third motor circuit conduit **74**, so as to bypass the radiator **64**. Flow through the third motor circuit conduit **74** is easier than flow through the radiator **64** (ie. there is less of a pressure drop associated with flow through the third conduit than there is with flow through the radiator **64**) and so bypassing the radiator **64** whenever possible, reduces the energy consumption of the pump **70**. By reducing the energy consumed by components in the vehicle **12** (FIG. **1**), the range of the vehicle can be extended, which is particularly advantageous in electric vehicles.

[0045] It will be noted that only a single radiator bypass valve **75** is provided for bypassing the radiator **64**. When the radiator bypass valve **75** is in the first position, all of the heat exchange fluid flow is directed through the second conduit **68**, through the radiator **64** and through the first conduit **66**. There is no net flow through the third conduit **74** because there is no net flow into the third conduit. Conversely, when the radiator bypass valve **75** is in the second position, all of the heat exchange fluid flow is directed through the third conduit **74** and back to the first conduit **66**. There is no net flow through the radiator **64** because there is no net flow into the radiator **64**. Thus, using only a single valve (ie. 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 third conduits **68** and **74** and another valve at the junction of the first and third conduits **66** and **74**. As a result of using one valve (ie. valve **75**) instead of two valves, the motor circuit **56** contains fewer components, thereby making the thermal management system **10** less expensive, simpler to make and to operate and more reliable. Furthermore by eliminating one valve, the energy required to move the heat exchange fluid through the motor circuit **56** is reduced, thereby reducing the energy consumed by the pump **70** and extending the range of the vehicle **12** (FIG. **1**).

[0046] The pump **70** may be positioned anywhere suitable, such as in the first motor circuit conduit **66**.

[0047] The elements that make up the motor circuit thermal load 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 system **28**, and the motor **14** may be downstream from the transmission control system **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**.

[0048] 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 all the thermal loads in the motor circuit **56**, so as to record the highest temperature of the heat exchange fluid.

Based on this temperature, a controller, shown at **78** can determine whether or not to position the radiator bypass valve **75** in a first position wherein the radiator bypass valve **75** transfers the flow of heat exchange fluid towards the radiator **64** and a second position wherein the radiator bypass valve **75** bypasses the radiator **64** and transfers the flow of heat exchange fluid through the third motor circuit conduit **74** back to the first motor circuit conduit **66**.

[0049] 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), 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) to the motor circuit **56**. In the embodiment shown the second cabin heating circuit conduit **82** extends to the third motor circuit conduit **74**. This is because the cabin heating heat exchanger **47** serves to cool the heat exchange fluid by some amount, so that the resulting cooled heat exchange fluid need not be passed through the radiator **64** in the motor circuit **56**. By reducing the volume of heat exchange fluid that passes through the radiator **64**, energy consumed by the pump **70** is reduced, thereby extending the range of the vehicle **12** (FIG. **1**). In an alternative embodiment, the second cabin heating circuit conduit **82** may extend to the second motor circuit conduit **68** downstream so that the heat exchange fluid contained in the second cabin heating circuit conduit **82** passes through the radiator **64**.

[0050] 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 system **28**.

[0051] 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** and not to transfer the fluid back to the motor circuit **56**. For example, when the fluid is being heated by the heater **32** it may be advantageous to not transfer the fluid back to the motor circuit **56** since the fluid in the motor circuit **56** is used solely for cooling the thermal load **61** and it is thus undesirable to introduce hot fluid into such a circuit. For the purpose of preventing fluid from being transferred from the cabin heating circuit **58** back to the motor circuit **56**, a 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 positionable in a first position wherein the valve **88** directs fluid flow towards the radiator **64** 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**.

[0052] 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 up the third conduit **84**.

[0053] 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 (ie.

[0054] 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 towards the radiator **64**. 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 (ie. 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 energy consumption is reduced 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.

[0055] Additionally, the valve **88** combined with the pump **86** permit isolating heated fluid in the cabin heating circuit **58** from the 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 radiator **64** to be cooled.

[0056] 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 cabin heating circuit heater **32**. 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**.

[0057] The battery circuit **60** is configured for controlling the temperature of the battery packs **16*a*** and **16*b*** 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 **16*a*** and **16*b*** and a thermal load outlet is shown at **100** downstream from the battery charge control module **42**.

[0058] The battery packs **16*a*** and **16*b*** are in parallel in the battery circuit **60**, which permits the fluid flow to each of the battery packs **16*a*** and **16*b*** to be selected individually so that each battery pack **16*a*** or **16*b*** 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 **16*a*** and **16*b*** 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 **16*a*** and **16*b***.

After the fluid has passed through the battery packs **16***a* and **16***b*, the fluid is brought into a single conduit which passes through the battery charge control module **42**. While the battery packs **16***a* and **16***b* are shown in parallel in the battery circuit **60**, they could be provided in series in an alternative embodiment.

[0059] 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 thermal load **96** in situations where the thermal load **96** requires heating. The battery circuit heater **108** may operate on current from a low voltage current source, such as the low voltage battery **40**. This is discussed in further detail further below.

[0060] 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.

[0061] 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**.

[0062] It will be noted that the flow in the battery circuit **60** is isolated from the flow in the motor circuit **56** with only one valve (ie. 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 (ie. 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 **60** has fewer components and is thus simpler, which can result in reduced cost and increased reliability for the therman management system **10**.

[0063] 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 to have the valve **114** should be in the first or second position and whether any devices (eg. the chiller **112**, the heater **108**) need to be operated to adjust the temperature of the fluid in the first conduit **102**.

[0064] 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** (ie. the evaporator **48**).

[0065] 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 wherein 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**.

[0066] At the downstream end of 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 upstream end of 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 upstream end of 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 heat exchanger **48**.

[0067] At the downstream end of 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 upstream end of 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 upstream end of 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**.

[0068] 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**.

[0069] A refrigerant pressure sensor **142** may be provided anywhere suitable in the cooling circuit **62**, such as on the first conduit **126** upstream from where the conduit **126** divides into the first and second branches **128** and **130**.

[0070] The pressure sensor **142** communicates pressure information from the cooling circuit **62** to the controller **78**.

[0071] 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 controlled by the controller **78**.

[0072] An expansion tank **124** is provided for removing gas that can accumulate in other components such as the radiator **64**. The expansion tank **124** may be positioned at the highest elevation of any fluid-carrying components of the thermal management system. The expansion tank **124** may be used as a point of entry for heat exchange fluid into the thermal management system **10** (ie. the system **10** may be filled with the fluid via the expansion tank **124**).

[0073] 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 and which each control one or more components of the thermal management system **10**, as well as other components optionally.

[0074] The logic used by the controller **78** to control the operation of the thermal management system **10** depends on which of several states the vehicle is in. The vehicle may be on-plug and off, which means that the vehicle itself is off (eg.

the ignition key is out of the ignition slot in the instrument panel) and is plugged into an external electrical source (eg. for recharging the battery packs **16***a* and **16***b*). The vehicle may be off-plug and off, which means that the vehicle itself is off and is not plugged into an external electrical source. The vehicle may be off-plug and on, which means that the vehicle itself is on and is not plugged into an external electrical source. The logic used by the controller **78** may be as follows:

[0075] The controller **78** attends to the cooling requirements of the thermal load **61** of the motor circuit **56** when the vehicle is off-plug and when the vehicle is on. The controller **78** determines a maximum permissible temperature (e.g., 50 degrees Celsius) for the heat exchange fluid and determines if the actual temperature of the heat exchange fluid exceeds the maximum permissible temperature (based on the temperature sensed by the temperature sensor **76**) by more than a selected amount (which is a calibrated value, and which could be 0 for example). If so, the controller operates the pump **70** to circulate the heat exchange fluid through the motor circuit **56** until a lower temperature is sensed at the temperature sensor **76** (e.g., 46 degrees Celsius). Initially when the vehicle enters the state of being off-plug and on, the controller **78** may default to a ‘cooling off’ mode wherein the pump **70** is not turned on, until the controller **78** has determined and compared the aforementioned temperature values. In the event that the vehicle is in a fault state, the controller **78** may enter a motor circuit cooling fault mode. When the controller **78** exits the fault state, the controller **78** may pass to the ‘cooling off’ mode.

[0076] The controller **78** attends to the heating and cooling requirements of the cabin heating circuit **58** when the vehicle is on-plug and when the vehicle is off-plug and on. The controller **78** may have 3 cabin heating modes. The controller **78** determines if the requested cabin temperature from the climate control system in the cabin **18** exceeds the temperature sensed by a temperature sensor in the evaporator **48** that senses the actual temperature in the cabin **18** by a selected calibrated amount. If so, and if the vehicle is either off plug and on or on plug and there is sufficient power available from the electrical source, and if the controller **78** determines if the temperature sensed by the temperature sensor **76** is higher than the requested cabin temperature by a selected calibrated amount. If the temperature sensed by the temperature sensor **76** is higher, then the controller **78** positions the cabin heating circuit valve **88** in the second position wherein flow is generated through the cabin heating circuit **58** from the motor circuit **56** and the controller **78** puts the cabin heating circuit heater **32** in the off position. These settings make up the first cabin heating mode. If the temperature sensed by the temperature sensor **76** is lower than the requested cabin temperature by a selected calibrated amount, then the controller **78** positions the cabin heating circuit valve **88** in the first position and turns on the pump **86** so that flow in the cabin heating circuit **58** is isolated from flow in the motor circuit **56**, and the controller **78** additionally turns on the cabin heating circuit heater **32** to heat the flow in the cabin heating circuit **58**. These settings make up the second cabin heating mode.

[0077] If the temperature sensed by the temperature sensor **76** is within a selected range of the requested temperature from the climate control system then the controller **78** positions the cabin heating circuit valve **88** in the second position so that flow in the cabin heating circuit **58** is not isolated from flow in the motor circuit **56**, and the controller turns the heater **32** on. These settings make up the third cabin heating mode. The selected range may be the requested temperature from the climate control system minus the selected calibrated value, to the requested temperature from the climate control system plus the selected calibrated value.

[0078] The default state for the controller **78** when cabin heating is initially requested may be to use the first cabin heating mode.

[0079] The controller **78** may have one cabin cooling mode. 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, and if the vehicle is either off plug and on or on plug and there is sufficient power available from the electrical source, then the controller **78** turns on the compressor **30** and moves the refrigerant flow control valve **138** to the open position so that refrigerant flows through the cabin cooling heat exchanger **48** to cool an air flow that is passed into the cabin **18**.

[0080] The thermal management system **10** will enter a cabin heating and cabin cooling fault mode when the vehicle is in a fault state.

[0081] When the climate control system in the cabin **18** is set to a ‘defrost’ setting, the controller **78** will enter a defrost mode, and will return to whichever heating or cooling mode the controller **78** was in once defrost is no longer needed.

[0082] The default mode for the controller **78** with respect to the cabin heating circuit **58** may be to have the cabin heating circuit valve **88** in the first position to direct flow towards the radiator, and to have the heater **32** off, the pump **86** off. The default mode for the controller **78** with respect to cooling the cabin **18** may to be to have the refrigerant flow control valve **138** in the closed position to prevent refrigerant flow through the cabin cooling heat exchanger **48**, and to have the compressor **30** off.

[0083] The controller **78** attends to the heating and cooling requirements of the battery circuit **60** when the vehicle is on-plug and is off, and when the vehicle is off-plug and is on. The controller **78** may have three cooling modes for cooling the battery circuit thermal load **96**. The controller **78** determines a desired battery pack temperature based on the particular situation, and determines if a first cooling condition is met, which is whether the desired battery pack temperature is lower than the actual battery pack temperature by a first selected calibrated amount.

[0084] If the first cooling condition is met, the controller **78** determines which of the three cooling modes the controller **78** will operate in by determining which, if any, of the following second and third cooling conditions are met.

[0085] The second condition is whether the temperature sensed by the temperature sensor **76** is lower than the desired battery pack temperature by at least a second selected calibrated amount DT2, 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 second condition is met, then the controller **78** operates in a first battery circuit cooling mode, wherein the controller **78** positions the battery circuit valve **114** in the first position wherein flow 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**. The first battery circuit cooling mode thus uses the radiator **68** to cool the battery circuit thermal load **96** via the motor circuit **56**.

[0086] The third cooling condition is whether the temperature sensed by the temperature sensor **76** is greater than the desired battery pack temperature by at least a third selected calibrated amount DT3, which may, for example, be related to the expected temperature drop associated with the chiller **112**. If the third cooling condition is met, then the controller **78** operates in a second battery circuit cooling mode 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**, and 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**.

[0087] If neither the second or third cooling conditions are met, (ie. if the temperature sensed by the temperature sensor **76** is greater than or equal to the desired battery pack temperature minus the second selected calibrated amount DT2 and the temperature sensed by the temperature sensor **76** is less than or equal to the desired battery pack temperature plus the third selected calibrated amount DT3, then the controller **78** operates in a third battery circuit cooling mode wherein the controller **78** positions the battery circuit valve **114** in the first position so that flow in the battery circuit **60** is not isolated from flow in the motor circuit **56**, and the controller **78** turns the chiller **112** on.

[0088] It will be understood that in any of the battery circuit cooling modes, the controller **78** turns the battery circuit heater **108** off.

[0089] The battery packs **16***a*, **16***b* can be cooled according to more than one upper temperature limit. For instance, when the vehicle **12** is on-plug and charging, the upper temperature limit can be set lower than when the vehicle **12** if off-plug and being operated. This is so that if the vehicle **12** is taken off plug when the battery temperature is at or near the on-plug upper temperature limit and cabin cooling is demanded from the HVAC system **46** at the same time, then the battery temperature is allowed to warm to the higher off-plug temperature limit so as to avoid both the battery chiller **112** and the cabin cooling heat exchanger (evaporator) **48** from demanding and competing for cooling from the compressor **30**. When the evaporator **48** and the chiller **112** compete for refrigerant from the compressor **30** it increases the amount of time needed for the HVAC system **46** to cool the cabin **18** down to a requested temperature. Furthermore, in at least some embodiments, the system could be configured to preferentially send refrigerant to the battery chiller **112** in the event that both the chiller **112** and the evaporator **48** were competing for refrigerant. This is because it may be considered more critical to ensure that the battery packs **16***a* and **16***b* remain at a temperature that avoids damage to them than it is to keep the vehicle occupants comfortable. This problem may be aggravated in hot climates, and/or if the cabin air control is set to intake a significant amount of fresh air, (as opposed to recirculating all or most cabin air).

[0090] FIG. **4** shows a portion of the battery circuit **60** including the battery circuit pump **106**, the battery circuit conduits **102**, **104**, the battery circuit temperature sensor **116**, as well as the battery packs **16***a*, **16***b* and the battery charge control module **42**. Heat exchange fluid flow is indicated by the arrows. Some components of the battery circuit **60** are omitted from this FIG. for clarity.

[0091] As mentioned, the external electrical power source **44** is for charging the battery packs **16***a*, **16***b*. The electrical source **44** can be provided at a charging station and can include an electrical plug that removably connects to the battery charge control module **42**. The electrical source **44** is shown in the FIG. as electrically connected to the battery charge control module **42**.

[0092] Also shown in FIG. **4** is the controller **78** as well as several functional components of the controller **78**. For clarity, not all components of the controller **78** are shown. The controller **78** is configured to detect when the battery charge control module **42** is connected to the electrical source **44** to charge the battery packs **16***a*, **16***b*. In this example, the controller **78** includes a limit selector **300** electrically connected to the battery charge control module **42**. The limit selector **300** can be part of the hardware or software that controls operation of the battery charge control module **42**. The limit selector **300** can include hardware (such as a logic circuit) and/or software (such as a processor-executable code). The limit selector **300** can be part of a larger control program of the thermal management system **10**.

[0093] The limit selector **300** selects a temperature limit for the battery circuit temperature sensor **116** with reference to whether the battery charge control module **42** is detected as connected to the electrical source **44**. The limit selector **300** selects a first battery circuit temperature limit (off-plug limit) **302** for use when the battery charge control module **42** is not connected to the electrical source **44** and selects a second battery circuit temperature limit (on-plug limit) **304** for use when the battery charge control module **42** is connected to the electrical source **44**. The second temperature limit **304** is lower than the first temperature limit **302**.

[0094] The first and second temperature limits **302**, **304** are upper limits, or maximum temperatures, that the controller **78** will allow at the battery circuit temperature sensor **116** before cooling the battery packs **16***a*, **16***b*, (e.g. using one of the methods discussed above). The first and second temperature limits **302**, **304** can be the upper limits of temperature ranges that also have lower limits for the controller **78** to reference to stop cooling the battery packs **16***a*, **16***b*. In this example, the first temperature limit **302** is 38 degrees Celsius and is the upper limit of a temperature range that has a lower limit of 36 degrees Celsius, and the second temperature limit **304** is 37 degrees Celsius and is the upper limit of another temperature range that has a lower limit of 35 degrees Celsius. Thus, the second temperature limit is lower than the first temperature limit by 1 degree Celsius. In other examples, the second temperature limit is lower than the first temperature limit by between about 1 and about 3 degrees Celsius. The first and second temperature limits **302**, **304** can be selected based on performance of an evaporator **48**, as well as other components, such as the compressor **30**. That is, if the evaporator **48** is capable of cooling the passenger cabin **18** relatively quickly, then a smaller difference (e.g., 1 degree Celsius) between the first and second temperature limits **302**, **304** can be selected, which corresponds to a shorter delay for cooling the battery packs **16***a*, **16***b*. If the evaporator **48** requires more time to cool the cabin **18**, then a larger difference (e.g., 3 degrees Celsius) between the first and second temperature limits **302**, **304** can be selected, reflecting a longer delay for cooling the battery packs **16***a*, **16***b*.

[0095] It will be noted that it is theoretically possible to set the on-plug upper temperature limit (i.e. the second temperature limit) to be much lower than the off-plug upper temperature limit (i.e. the first temperature limit) in order to maximize the amount of delay that would be possible before having to cool the battery packs **16***a* and **16***b* when the vehicle is taken off-plug. This would potentially negatively impact the vehicle's MPGe rating, however, which takes into account the amount of energy consumed by the vehicle while on-plug, among other things. Accordingly, a smaller difference between the on-plug and off-plug upper temperature limits may be provided thereby making for a smaller available delay so as to improve the MPGe rating for the vehicle. A difference of about 1 to about 3 degrees Celsius has been found to be acceptable for most climates in the sense that such a difference permits a vehicle occupant to pull down the cabin temperature by an acceptable amount before the battery packs **16***a* and **16***b* demand cooling via the refrigerant system while keeping the overall on-plug energy consumption relatively low so as to keep any negative impact to the MPGe rating for the vehicle relatively low.

[0096] The controller **78** is configured to operate the battery circuit **60** to conform to the selected temperature limit **302** or **304** for the battery circuit temperature sensor **116**. As previously discussed with respect to the battery circuit cooling modes, the controller **78** can operate or refrain from operating any of the fluid-circuit components of the battery circuit **60** and the motor circuit **56**, including the pump **106**, valve **114**, chiller **112**, chiller flow valve **140**, compressor **30**, and radiator fan **144**, to cool the battery circuit **60**. A battery circuit cooling program **306** can be included in the controller **78** to ensure that the temperature of the battery circuit **60** as measured by the battery circuit temperature sensor **116** remains about below the temperature limit **302** or **304** selected by the limit selector **300**.

[0097] The battery circuit cooling program **306** can include hardware or software components, such as a logic circuit, an RLC circuit, and processor-executable code. In this example, the battery circuit cooling program **306** is a program executed by a processor of the controller **78**. Such a program can include one or more of a standalone executable program, a subroutine, a function, a module, a class, an object, or another programmatic entity. The battery circuit cooling program **306** can be part of a larger control program of the thermal management system **10**. The battery circuit cooling program **306** can include logic of the limit selector **300**. The battery circuit cooling program **306** has available as input the temperature sensed by the battery circuit temperature sensor **116**, and can output a commanded speed for the battery circuit pump **106**, as well as a control command for the chiller **112**, such as a position of the flow control valve **140** and/or a requested capacity from the compressor **30**. The battery circuit cooling program **306** can have additional inputs and outputs as well.

[0098] FIG. **5** shows a method **320** that can be performed by the controller **78**, and specifically, by the limit selector **300** and the battery circuit cooling program **306**. The method **320** can cool the battery according to two different temperature limits.

[0099] At **321**, it is determined whether the vehicle **12** is on-plug and the battery packs **16***a,* **16***b* are being charged. This can be determined by the limit selector **300**.

[0100] At **322**, if the vehicle **12** is on-plug, the ambient temperature can be sensed and it can be determined whether the ambient temperature is high enough to expect demand on the compressor **30** for cabin cooling when the vehicle **12** is taken off plug. The controller **78** can compare the temperature sensed by the ambient temperature sensor **180** to a threshold, such as 21 degrees Celsius.

[0101] When the vehicle **12** is on-plug and the battery packs **16***a,* **16***b* are being charged and, optionally, the ambient temperature is higher than the threshold, the second, lower temperature limit **304** is selected, at **324**. Continuing the above example, the limit selector **300** selects 37 degrees Celsius as the temperature limit.

[0102] When the vehicle **12** is off-plug and the battery packs **16***a,* **16***b* are being discharged to operate the vehicle **12**, the first, higher temperature limit **302** is selected, at **326**. Continuing the above example, the limit selector **300** selects 38 degrees Celsius as the temperature limit. Since the passenger cabin **18** may also be undergoing cooling via the evaporator **48** at this time, selection of the higher temperature limit of 38 degrees Celsius means that cooling of the battery will be delayed to allow for full cooling capacity to reach the passenger cabin **18**, in case the vehicle **12** was taken off plug at or near the on-plug limit of 37 degrees Celsius.

[0103] At **328**, it is then determined whether the battery packs **16***a,* **16***b* have reached the selected temperature limit. The battery circuit cooling program **306** compares the temperature of the battery circuit temperature sensor **116** to the selected temperature limit. If the selected temperature limit has not been reached, then the method **320** loops back to **321**.

[0104] If the selected temperature limit has been reached, then the battery packs **16***a,* **16***b* are cooled, at **330**. The battery circuit cooling program **306** operates the battery circuit **60** as described elsewhere herein, such as by using the chiller **112** or radiator **64** to cool heat exchange fluid and pumping the fluid through a battery circuit **60**. At this time, the battery packs **16***a,* **16***b,* the battery charge control module **42**, and other components of the battery circuit thermal load **96** are cooled. The method **320** then returns to **321** to again determine whether the vehicle **12** is on or off plug.

[0105] In other examples, the steps of the method **320** can be performed in an order other than described. In still other examples, steps can be combined or further separated into further sub-steps.

[0106] In the above example method **320**, different temperature limits are used to delay of cooling the battery packs **16***a,* **16***b* when the vehicle **12** is taken off plug. In another example method, a timer is used when the vehicle **12** is taken off plug to delay of cooling the battery packs **16***a,* **16***b*. The timer can be set to approximate an allowable rise in temperature for the battery packs **16***a,* **16***b.*

[0107] FIG. **6** shows a chart of cooling the battery packs **16***a,* **16***b* when taking the vehicle **12** from on-plug to off-plug, and when using the same temperature limit for the battery packs **16***a,* **16***b* for on-plug and off-plug.

[0108] A battery temperature curve **340** represents the temperature sensed by the battery circuit temperature sensor **116**. A cabin temperature curve **350** represents the temperature of the passenger cabin **18**, which, when cooling is of concern, can be measured at the evaporator **48**. The curves **340**, **350** have separate vertical temperature scales and share the same horizontal time scale.

[0109] While the vehicle **12** is on-plug, the battery temperature curve **340** rises as the battery circuit thermal load **96** heats due to waste heat from charging of the battery packs **16***a,* **16***b,* and then falls due to the controller **78** commanding cooling of the battery circuit **60**. These rising and falling cycles occur between a lower temperature limit LTL (e.g., 36 degrees Celsius) and an upper temperature limit HTL (e.g., 38 degrees Celsius). At this time, since the vehicle **12** is not in use and the cabin temperature is not requested to be lowered, the cabin temperature curve **350** remains at ambient (e.g., 30 degrees Celsius).

[0110] Then, at time Toff, the vehicle **12** is taken off-plug and operated. At the same time, the cabin temperature is requested to be lowered via a cabin control. However, in this example, the battery temperature curve **340** is at or near the upper temperature limit HTL at time Toff. Therefore, both the evaporator **48** and chiller **112** demand cooling capacity from the compressor **30** to respectively cool the cabin **18** and the battery packs **16***a,* **16***b.* It is not until a later time T2 when the battery packs **16***a,* **16***b* have reached the lower temperature limit LTL that the evaporator **48** can be provided the full cooling capacity of the compressor **30**. Hence, the cabin temperature curve **350** drops at a steeper rate when the battery packs **16***a,* **16***b* are no longer being cooled.

[0111] FIG. **7** shows a chart of cooling the battery packs **16***a,* **16***b* when taking the vehicle **12** from on-plug to off-plug, and when using different temperature limits for the battery packs **16***a,* **16***b* for on-plug and off-plug.

[0112] A battery temperature curve **360** represents the temperature sensed by the battery circuit temperature sensor **116**. A cabin temperature curve **370** represents the temperature of the passenger cabin **18**, which can be measured at the evaporator **48**. The curves **360**, **370** have separate vertical temperature scales and share the same horizontal time scale. The curves **360**, **370** have the same scales as the respective curves **340**, **350** of FIG. **6**.

[0113] While the vehicle **12** is on-plug, the battery temperature curve **360** rises and falls similar to the curve **340**. However, these rising and falling cycles occur between a lower temperature limit LTL' (e.g., 35 degrees Celsius) and the second temperature limit **304** (e.g., 37 degrees Celsius) described above. At this time, since the vehicle **12** is not in use and the cabin temperature is not requested to be lowered, the cabin temperature curve **370** remains at ambient (e.g., 30 degrees Celsius).

[0114] Then, at time Toff, the vehicle **12** is taken off-plug and operated. At essentially the same time, the cabin temperature is requested to be lowered via a cabin control. However, at the same time, the limit selector **300** determines that the vehicle **12** has been taken off-plug and selects the first temperature limit **302** (e.g., 38 degrees Celsius) as the upper temperature limit for the battery packs **16***a,* **16***b,* and optionally further selects a corresponding low temperature limit LTL (e.g., 36 degrees Celsius). Accordingly, the temperature sensed by the battery circuit temperature sensor **16** is permitted to continue to rise, while the cabin **18** is cooled via the refrigerant system so that all of the refrigerant flow is used to cool the cabin **18**. At time T3, the battery circuit temperature sensor **116** reports that the first temperature limit **302** has been reached, and so cooling of the battery packs **16***a,* **16***b* is begins. Thus, between times Toff and T3, the full cooling capacity of the compressor **30** can be provided to the evaporator **48** to meet the cooling demand of the cabin **18**. For the sake of comparison, FIG. **7** also shows the time T2, at which it can be seen that the cabin temperature is lower than that of FIG. **6**. Moreover, the curve **370** exhibits a lower cabin temperature between times Toff and T3 than the curve **350** does over the same time range, which illustrates an advantage of using the different temperature limits **302**, **304**, namely, increasing the effectiveness of cabin cooling.

[0115] As a separate consideration from the temperature ranges used for the battery circuit, different temperature limits when the vehicle **12** is on-plug and off-plug can also be referenced when cooling the motor circuit **56**. Since the motor **14** is not operating and consequently not generating heat, when the vehicle **12** is on-plug, a higher temperature limit for the motor circuit **56** can be used to prevent unnecessary cooling of the motor circuit **56**. This is particularly true in the event that the ambient air temperature is sufficiently low that the ambient air can bring the motor **14** (or more generally, the motor circuit thermal load) down to an acceptable temperature as the vehicle sits while on-plug.

[0116] FIG. **8** shows a portion of the motor circuit **56** including the motor circuit pump **70**, the DC/DC converter **34**, the transmission control module **28**, the motor **14**, and the motor circuit temperature sensor **76**. Heat exchange fluid flow is indicated by the arrows. Some components of the motor circuit **56** are omitted from this FIG. for clarity.

[0117] The controller **78** is configured to detect when the battery charge control module **42** is connected to the electrical source **44** to charge the battery packs **16***a,* **16***b.* In this example, the controller **78** includes the limit selector **300**, discussed above, electrically connected to the battery charge control module **42**. For clarity, not all components of the controller **78** are shown.

[0118] The limit selector **300** selects a temperature limit for the motor circuit temperature sensor **76** with reference to whether the battery charge control module **42** is detected as connected to the electrical source **44**. The limit selector **300** selects a first motor circuit temperature limit (off-plug limit) **402** when detecting that the battery charge control module **42** is not connected to the electrical source **44** and selects a second motor circuit temperature (on-plug limit) **404** when detecting that the battery charge control module **42** is connected to the electrical source **44**. Since the motor circuit **56** does not typically receive significant heat when the vehicle **12** is on-plug, the second motor circuit temperature limit **404** can be set higher than the first motor circuit temperature limit **402** thereby preventing unnecessary cooling of the motor circuit **56** at least some of which would have taken place passively as the vehicle sat on-plug anyway.

[0119] The first and second motor circuit temperature limits **402**, **404** are upper limits, or maximum temperatures, that the controller **78** will allow at the motor circuit temperature sensor **76** before commanding the pump **70** to operate at a selected flow rate or speed to circulate fluid in the motor circuit **56** (and also optionally operating the radiator fan **144**) to cool the circulated fluid. It will be noted that below these temperature limits **402** and **404**, in some embodiments, the controller **78** will continue to operate the pump **70** (e.g. at about 40% duty cycle) when the vehicle is on plug. The third and fourth temperature limits **402**, **404** can be the upper limits of temperature ranges that also have lower limits for the controller **78** to reference to stop cooling the motor circuit **56**. In this example, the first temperature limit **402** is 50 degrees Celsius and is the upper limit of a temperature range that has a lower limit of 46 degrees Celsius, and the second temperature limit **404** is 70 degrees Celsius and is the upper limit of another temperature range that has a lower limit of 66 degrees Celsius. Thus, the second temperature limit is higher than the first temperature limit by 20 degrees Celsius. In other examples, the second temperature limit is higher than the first temperature limit by other amounts, such as 10 or 15 degrees Celsius. By reducing the amount of energy consumed while on-plug, the MPGe rating of the vehicle can be increased.

[0120] The controller **78** is configured to operate the motor circuit **56** to conform to the selected temperature limit **402** or **404** for the motor circuit temperature sensor **76**. For example, the controller **78** can operate or refrain from operating any of the fluid-circuit components of the motor circuit **56**, including the pump **70**, the radiator bypass valve **75**, and the radiator fan **144**, to cool the motor circuit **56**. A motor circuit cooling program **406** can be included in the controller **78** to ensure that the temperature of the motor circuit **56** as measured by the motor circuit temperature sensor **76** remains about below the temperature limit **402** or **404** selected by the limit selector **300**.

[0121] The motor circuit cooling program **406** can be similar to the above-mentioned battery circuit cooling program **306**. The motor circuit cooling program **406** can be part of a larger control program of the thermal management system **10**. The motor circuit cooling program **406** can include logic of the limit selector **300**. The motor circuit cooling program **406** has available as input the temperature sensed by the motor circuit temperature sensor **76**, and can output a commanded speed for the motor circuit pump **70** and a commanded speed for the radiator fan **144**. The motor circuit cooling program **406** can have additional inputs and outputs as well.

[0122] FIG. **9** shows a method **420** that can be performed by the controller **78**, and specifically, by the limit selector **300** and the motor circuit cooling program **406**. The method **420** can cool the motor circuit **56** according to two different temperature limits.

[0123] At **421**, it is determined whether the vehicle **12** is on-plug. This can be determined by the limit selector **300**.

[0124] When the vehicle **12** is on-plug, the fourth, higher temperature limit **404** is selected, at **424**. Continuing the above example, the limit selector **300** selects 70 degrees Celsius as the temperature limit.

[0125] When the vehicle **12** is off-plug and operating such that the motor **14** and other components in the motor circuit **56** are generating heat, the third, lower temperature limit **402** is selected, at **426**. Continuing the above example, the limit selector **300** selects 50 degrees Celsius as the temperature limit.

[0126] At **428**, it is then determined whether the motor circuit **56** has reached the selected temperature limit. The motor circuit cooling program **406** compares the temperature of the motor circuit temperature sensor **76** to the selected temperature limit. If the selected temperature limit has not been reached, then the method **420** loops back to **421**.

[0127] If the selected temperature limit has been reached, then the motor circuit is cooled, at **430**. The motor circuit cooling program **406** operates the motor circuit **56** as described elsewhere herein, such as by operating the pump **70** and radiator fan **144** to cool heat exchange fluid and pump the fluid through a motor circuit **56**. The motor circuit thermal load **61**, namely, the motor **14**, the transmission control module **28**, and the DC/DC converter **34**, is thus cooled. The method **420** then returns to **421** to again determine whether the vehicle **12** is on or off plug.

[0128] In other examples, the steps of the method **420** can be performed in an order other than described. In still other examples, one or more of the steps can be combined or further separated into sub-steps.

[0129] The different on-plug and off-plug temperature limits for the motor circuit **56** can be used in conjunction with the different on-plug and off-plug temperature limits for the battery circuit **60**.

[0130] The controller **78** may have three battery circuit heating modes. The controller **78** determines a desired battery circuit thermal load temperature based on the particular situation, and determines whether a first heating condition is met, which is whether the desired battery pack temperature is higher than the actual battery pack temperature by a first selected calibrated amount. If the first heating condition is met, the controller **78** determines which of the three heating modes the controller **78** will operate in by determining which, if any, of the following second and third heating conditions are met. The second heating condition is whether the temperature sensed by the temperature sensor **76** is higher than the desired battery pack temperature by a second selected calibrated amount that may, for example, be related to the expected temperature drop of the fluid as the fluid flows from the temperature sensor **76** to the battery circuit thermal load **96**. If the second condition is met, then the controller **78** operates in a first battery circuit heating mode, wherein the controller **78** positions the battery circuit valve **114** in the first position wherein flow is generated through the battery circuit **60** from the motor circuit **56** and the controller **78** turns the battery circuit heater **32** off.

[0131] The third heating condition is whether the temperature sensed by the temperature sensor **76** is lower than the desired battery pack temperature by at least a third selected calibrated amount, which may, for example, be related to the expected temperature rise associated with the battery circuit heater **108**. If this third heating condition is met, then the controller **78** operates in a second battery circuit heating mode 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**, and the controller **78** additionally turns on the battery circuit heater **108** to heat the flow in the battery circuit **60**.

[0132] If neither the second or third conditions are met, (i.e. if the temperature sensed by the temperature sensor **76** is less than or equal to the desired battery pack temperature plus the second selected calibrated amount and the temperature sensed by the temperature sensor **76** is greater than or equal to the desired battery pack temperature minus the third selected calibrated amount, then the controller **78** operates in a third battery circuit heating mode wherein the controller **78** positions the battery circuit valve **114** in the first position so that flow in the battery circuit **60** is not isolated from flow in the motor circuit **56**, and the controller **78** turns the battery circuit heater **108** on.

[0133] The default state for the controller **78** when battery circuit thermal load heating is initially requested may be to use the first battery circuit heating mode.

[0134] The thermal management system **10** will enter a battery circuit heating and cooling fault mode when the vehicle is in a fault state.

[0135] When the vehicle is off-plug, the controller **78** heats the battery circuit thermal load **96** using only the first battery circuit heating mode.

[0136] The default state for the controller **78** when the vehicle is turned on is to position the battery circuit valve **114** in the first position so as to not generate fluid flow through the battery circuit **60**.

[0137] The controller **78** may operate using several other rules in addition to the above. For example the controller **78** may position the radiator bypass valve **75** in the first position to direct fluid flow through the radiator **64** if the temperature of the fluid sensed at sensor **76** is greater than the maximum acceptable temperature for the fluid plus a selected calibrated value and the cabin heating circuit valve **88** is in the first position and the battery circuit valve **114** is in the first position.

[0138] The controller **78** may also position the radiator bypass valve **75** in the first position to direct fluid flow through the radiator **64** if the temperature of the fluid sensed at sensor **76** has risen to be close to the maximum acceptable temperature for the fluid plus a selected calibrated value and the cabin heating circuit valve **88** is in the second position and the battery circuit valve **114** is in the second position.

[0139] In the event of an emergency battery shutdown, the controller **78** will shut off the compressor **30** and will turn on the cabin heating circuit heater **32** so as to bleed any residual voltage.

[0140] The temperature of the battery packs **16***a* and **16***b* may be maintained above their minimum required temperatures by the controller **78** through control of the refrigerant flow control valve **140** to the chiller **112**. The temperature of the evaporator may be maintained above a selected temperature which is a target temperature minus a calibrated value, through opening and closing of the refrigerant flow control valve **138**. The speed of the compressor **30** will be adjusted based on the state of the flow control valve **140** and of the flow control valve **138**.

[0141] The controller **78** is programmed with the following high level objectives and strategies using the above described modes. The high level objectives include:

[0142] A. control the components related to heating and cooling of the battery circuit thermal load **96** to maintain the battery packs **16***a* and **16***b* and the battery charge control module **42** within the optimum temperature range during charging and vehicle operation;

[0143] B. maintain the motor **14**, the transmission control system **28** and the DC/DC converter **34** at their optimum temperature ranges;

[0144] C. control the components related to heating and cooling the cabin **18** based on input from the climate control system; and

[0145] D. operate with a goal of maximizing vehicle range while meeting vehicle system requirements.

[0146] The controller **78** uses the following high level strategy on-plug:

[0147] When the vehicle is on-plug and is off, the controller **78** pre-conditions the battery packs **16***a* and **16***b* if required. Pre-conditioning entails bringing the battery packs **16***a* and **16***b* into a temperature range wherein the battery packs **16***a* and **16***b* are able to charge more quickly.

[0148] The controller **78** determines the amount of power available from the electrical source for temperature control of the battery packs **16***a* and **16***b,* 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 **16***a* and **16***b* 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 FIG. **3**). If sufficient power is available from the electrical source, the battery packs **16***a* and **16***b* may be charged while simultaneously being conditioned (ie. while simultaneously being cooled or heated to remain within their selected temperature range). If the battery packs **16***a* and **16***b* reach their fully charged state, battery pack conditioning may continue, so as to bring the battery packs **16***a* and **16***b* to their selected temperature range for efficient operation.

[0149] When the vehicle is on-plug the battery circuit heater **108** may be used to bring the battery packs **16***a* and **16***b* up to a selected temperature range, as noted above. In one of the heating modes 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**.

[0150] The cabin may be pre-conditioned (ie. heated or cooled while the vehicle is off) when the vehicle is on-plug and the state of charge of the battery packs **16***a* and **16***b* is greater than a selected value.

[0151] If the vehicle is started while on-plug, the controller **78** may continue to condition the battery packs **16***a* and **16***b,* 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.

[0152] When the vehicle is off-plug, battery pack heating may be achieved solely by using the heat in the fluid from the motor circuit (ie. without the need to activate the battery circuit heater **108**). Thus, while the vehicle is off-plug and on and the battery packs **16***a* and **16***b* 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 **16***a* and **16***b* 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.

[0153] 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 the open position, and by running the compressor **30**, as described above in one of the three cooling modes for the battery circuit **60**.

[0154] It will be noted that the battery packs **16***a* and **16***b* 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 **16***a* and **16***b.*

[0155] Reference is made to FIG. **3**, which shows a graph of battery pack temperature vs. time to highlight several of the rules which the controller **78** (FIG. **2**) follows. In situations where the vehicle is on-plug and the battery packs **16***a* and **16***b* are below a selected minimum charging temperature Tcmin (FIG. **3**), the controller **78** will heat the battery packs **16***a* and **16***b* prior to charging them. Once the battery packs **16***a* and **16***b* reach the minimum charging temperature Tcmin, some of the power from the electrical source may be used to charge the battery packs **16***a* and **16***b,* and some of the power from the electrical source may continue to be used to heat them. When the battery packs **16***a* and **16***b* reach a minimum charge only temperature Tcomin, the controller **78** may stop using power from the electrical source to heat the battery packs **16***a* and **16***b* 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.

[0156] While charging, the controller **78** may precondition the battery packs **16***a* and **16***b* for operation of the vehicle. Thus, the controller **78** may bring the battery packs **16***a* and **16***b* to a desired minimum operating temperature Tomin while on-plug and during charging.

[0157] In situations where the vehicle is on-plug and the battery packs **16***a* and **16***b* are above a selected maximum charging temperature Tcmax, the controller **78** will cool the battery packs **16***a* and **16***b* prior to charging them. Once the battery packs **16***a* and **16***b* 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 **16***a* and **16***b* below the temperature Tcmax. Tcmax may be, for example, 30 degrees Celsius.

[0158] The battery packs **16***a* and **16***b* 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 **16***a* and **16***b* 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 **16***a* and **16***b* may be permitted during operation after charging to rise from the temperature Tcmax until they reach the temperature Tomax.

[0159] The maximum and minimum operating temperatures Tomax and Tomin define an example of an acceptable operating range for the battery packs **16***a* and **16***b*. In situations where the battery packs **16***a* and **16***b* 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 **16***a* and **16***b*) above and below the noted 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 **16***a* and **16***b* 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.

[0160] It will be noted that the pumps **70**, **86** and **106** are variable flow rate pumps. In this way they can be used to adjust the flow rates of the heat exchange fluid through the motor circuit **56**, the cabin heating circuit **58** and the battery circuit **60**. By controlling the flow rate generated by the pumps **70**, **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.

[0161] 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**.

[0162] Throughout this disclosure, the controller **78** is referred to as turning on devices (eg. the battery circuit heater **108**, the chiller **112**), turning off devices, or moving devices (eg. 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 chiller 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 on the device.

[0163] 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 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 suitable type of heat exchanger, (e.g. a different type of heat exchanger that still uses refrigerant).

[0164] 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.

[0165] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

1. A thermal management system for a vehicle, the vehicle including a traction motor and a battery pack, the thermal management system comprising:

- a battery circuit for cooling a battery circuit thermal load including the battery pack;
- a battery circuit temperature sensor positioned to sense a temperature relating to a temperature of the battery circuit thermal load; and
- a controller configured to control the battery circuit to maintain the temperature sensed by the battery circuit temperature sensor below a first battery circuit temperature limit when the controller detects that the vehicle is not connected to an external electrical source, and to maintain the temperature sensed by the battery circuit temperature sensor below a second battery circuit temperature limit that is lower than the first battery circuit temperature limit when the controller detects that the vehicle is connected to the external electrical source.

2. A thermal management system as claimed in claim **1**, further comprising a battery charge control module, that controls electrical current sent to the battery pack from the external electrical source, wherein the battery charge control module makes up part of the battery circuit thermal load.

3. A thermal management system as claimed in claim **1**, wherein the vehicle includes a passenger cabin and the system further comprises:

a first heat exchanger positioned to cool fluid in the battery circuit;

a second heat exchanger positioned to cool an airflow leading to the passenger cabin; and

a compressor, positioned to compress refrigerant and to send the refrigerant through a refrigerant circuit leading to the first and second heat exchangers.

4. A thermal management system as claimed in claim **3**, wherein the first heat exchanger is a chiller and the second heat exchanger is an evaporator.

5. A thermal management system as claimed in claim **3**, wherein the first and second battery circuit temperature limits are selected based on at least one property of the second heat exchanger.

6. A thermal management system as claimed in claim **3**, wherein the first and second battery circuit temperature limits are selected based at least in part on how quickly the second heat exchanger can reduce the temperature of the passenger cabin.

7. A thermal management system as claimed in claim **1**, wherein the second battery circuit temperature limit is lower than the first temperature limit by between about 1 and about 3 degrees Celsius.

8. A thermal management system as claimed in claim **1**, wherein the second battery circuit temperature limit is lower than the first temperature limit by about 1 degree Celsius.

9. A thermal management system as claimed in claim **1**, further comprising:

a motor circuit for cooling a motor circuit thermal load including the traction motor, the motor circuit including a motor circuit pump; and

a motor circuit temperature sensor positioned to sense a temperature relating to a temperature of the motor circuit thermal load,

wherein the controller is further configured to control the motor circuit to maintain the temperature sensed by the motor circuit temperature sensor below a first motor circuit temperature limit when the controller detects that the vehicle is not connected to an external electrical source, and to maintain the temperature sensed by the motor circuit temperature sensor below a second motor circuit temperature limit that is higher than the first motor circuit temperature limit when the controller detects that the vehicle is connected to an external electrical source.

10. A thermal management system as claimed in cooling a battery circuit thermal load for a battery circuit of a vehicle, the vehicle including a traction motor and a battery pack that is at least part of the battery circuit thermal load, the method comprising:

cooling the battery circuit thermal load to maintain a temperature of the battery circuit thermal load below a first battery circuit temperature limit while not charging the battery pack using an external electrical source; and

cooling the battery circuit thermal load to maintain the temperature of the battery circuit thermal load below a second battery circuit temperature limit, the second battery circuit temperature limit being lower than the first battery circuit temperature limit while charging the battery pack using an external electrical source.

11. A method as claimed in claim **10**, wherein the vehicle includes:

a passenger cabin;

a first heat exchanger positioned to cool fluid in the battery circuit;

a second heat exchanger positioned to cool an airflow leading to the passenger cabin; and

a compressor, positioned to compress refrigerant and to send the refrigerant through a refrigerant circuit leading to the first and second heat exchangers.

12. A method as claimed in claim **11**, wherein the first heat exchanger is a chiller and the second heat exchanger is an evaporator.

13. A method as claimed in claim **11**, wherein the first and second battery circuit temperature limits are selected based on at least one property of the second heat exchanger.

14. A method as claimed in claim **11**, wherein the first and second battery circuit temperature limits are selected based at least in part on how quickly the second heat exchanger can reduce the temperature of the passenger cabin.

15. A method as claimed in claim **10**, wherein the second battery circuit temperature limit is lower than the first temperature limit by between about 1 and about 3 degrees Celsius.

16. A method as claimed in claim **10**, wherein the second battery circuit temperature limit is lower than the first temperature limit by about 1 degree Celsius.

17. A method as claimed in claim **10**, further comprising:

cooling the motor circuit thermal load to maintain a temperature of the motor circuit thermal load below a first motor circuit temperature limit while not charging the battery pack using an external electrical source; and

cooling the motor circuit thermal load to maintain the temperature of the motor circuit thermal load below a second motor circuit temperature limit, the second motor circuit temperature limit being higher than the first motor circuit temperature limit while charging the battery pack using an external electrical source.

18. A thermal management system for an electric vehicle, the electric vehicle including a traction motor, a battery, a battery charge control module, and a passenger cabin, the thermal management system comprising:

a motor circuit for cooling a motor circuit thermal load including the traction motor;

a motor circuit temperature sensor positioned to sense a temperature of fluid in the motor circuit; and

a controller configured to control the motor circuit to maintain the temperature sensed by the motor circuit temperature sensor below a first motor circuit temperature limit when the controller detects that the vehicle is not connected to an external electrical source, and to maintain the temperature sensed by the motor circuit temperature sensor below a second motor circuit temperature limit that is higher than the first motor circuit temperature limit when the controller detects that the vehicle is connected to an external electrical source.

* * * * *