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(54) **HVAC SYSTEM CONTROLLED BY A BATTERY MANAGEMENT SYSTEM**

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CPC ..... **B60H 1/00428** (2013.01); **H01M 10/482** (2013.01); **F25B 27/00** (2013.01); **Y02E 60/12** (2013.01); **B60P 3/20** (2013.01)

USPC ..... **62/236; 62/243; 62/244; 165/43**

(58) **Field of Classification Search**

USPC ..... 62/236, 243, 244; 165/42, 43, 202, 240; 701/22, 36; 320/134, 135

See application file for complete search history.

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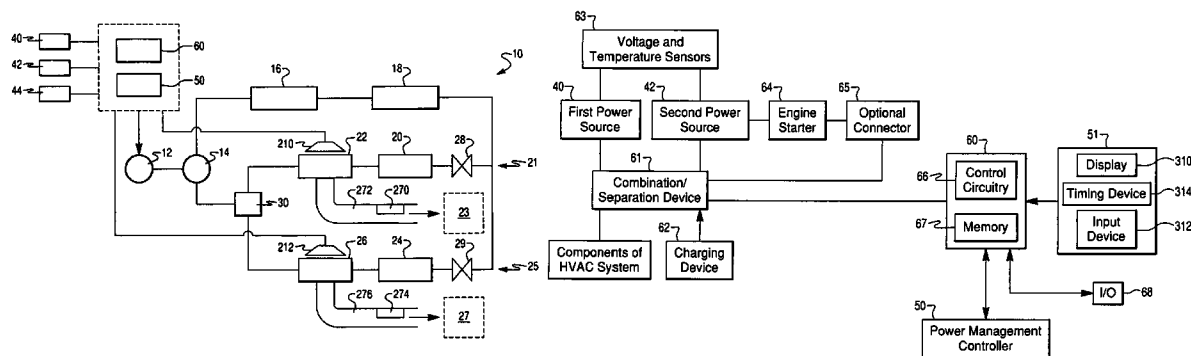
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**ABSTRACT**

An HVAC system to be installed in a vehicle comprises a battery management controller. The battery management controller comprises at least one connection for electrically coupling a first power source with a first voltage; at least one connection for electrically coupling a second power source with a second voltage; and a first memory storage device configured to record data collected by the battery management controller. The battery management controller is configured to run a temperature control system and to supply power to the temperature control system from a combination of the first and second power sources with a combined voltage, and wherein the second power source is disconnected when the combined voltage drops below a predetermined amount.

**7 Claims, 30 Drawing Sheets**



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Fig. 1

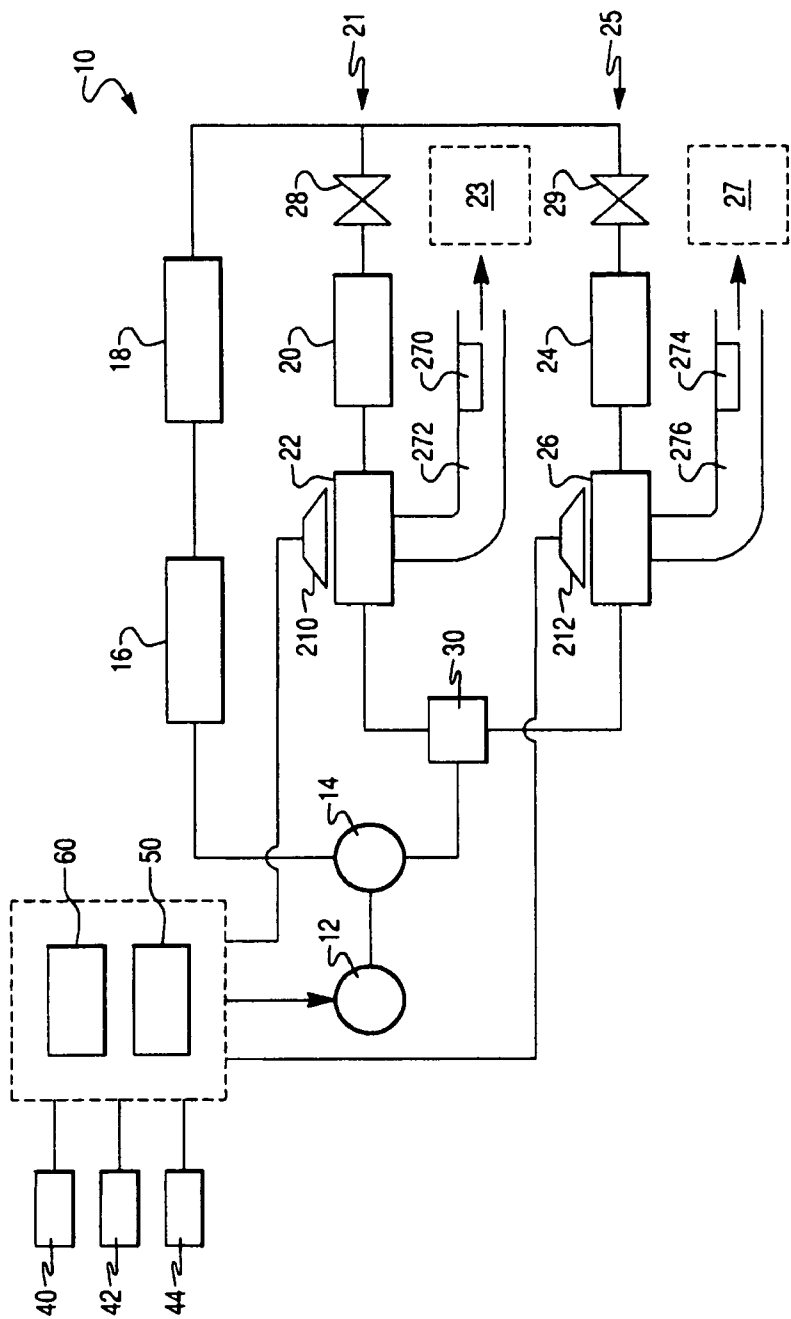


Fig. 2

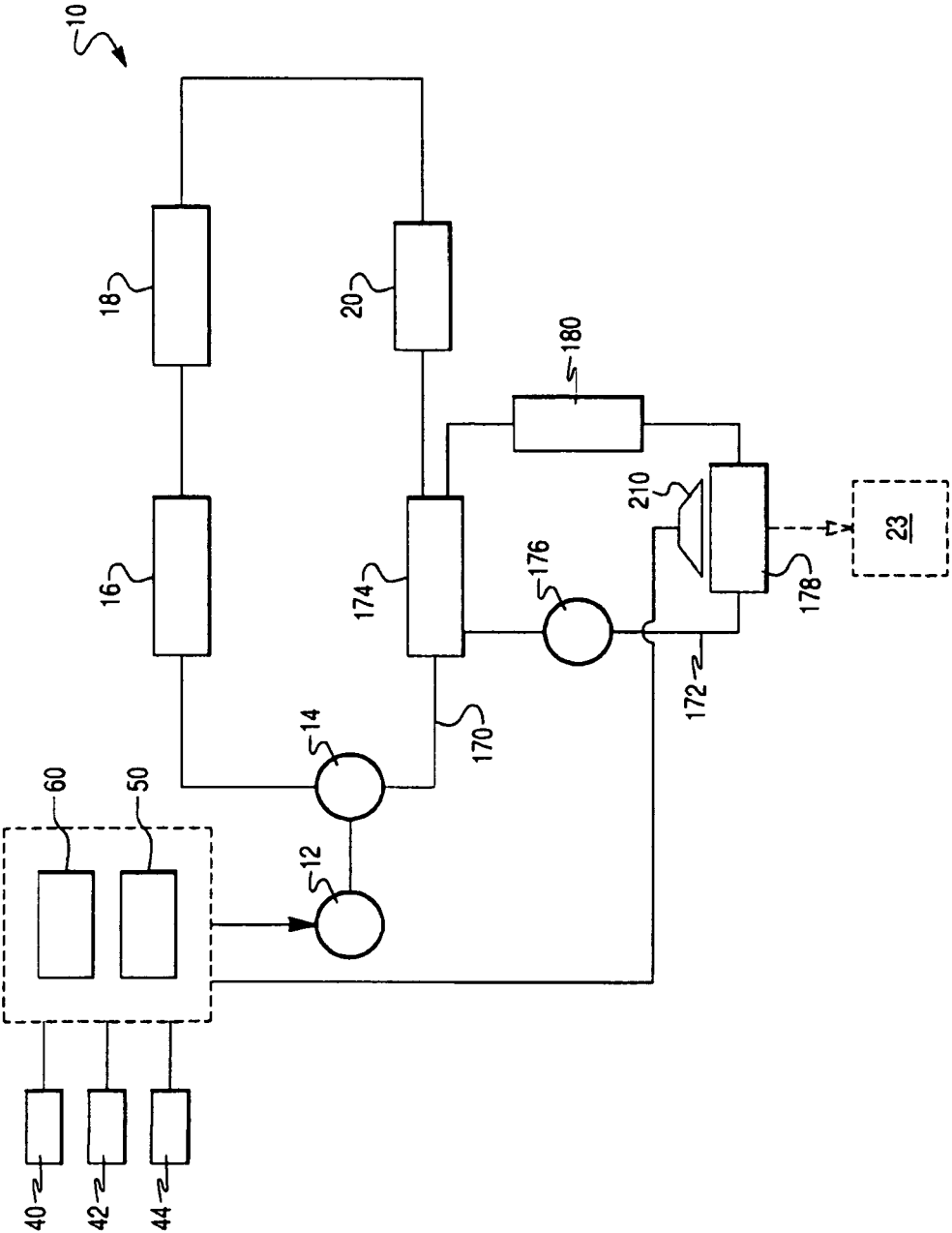


Fig. 3

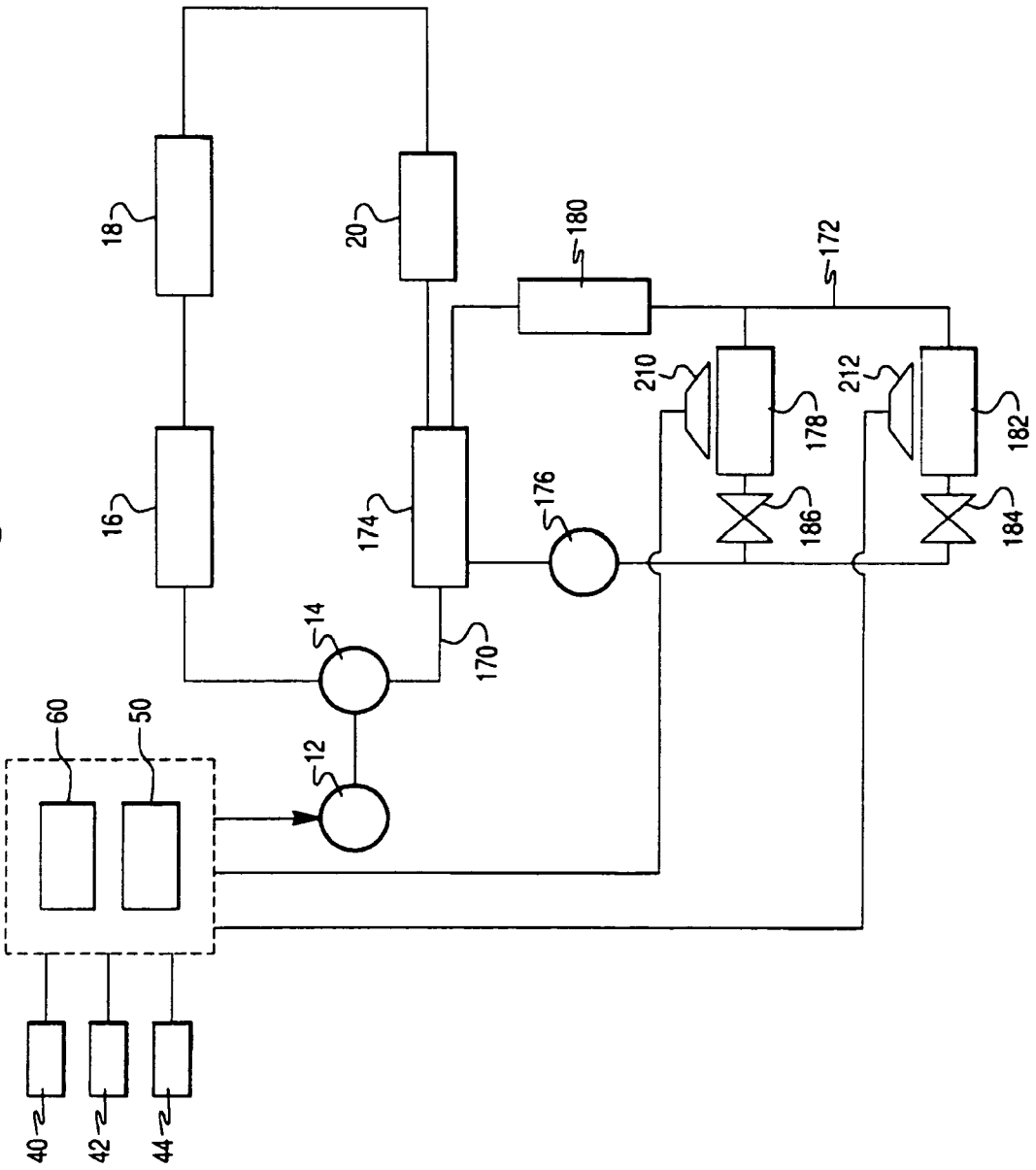


Fig. 4

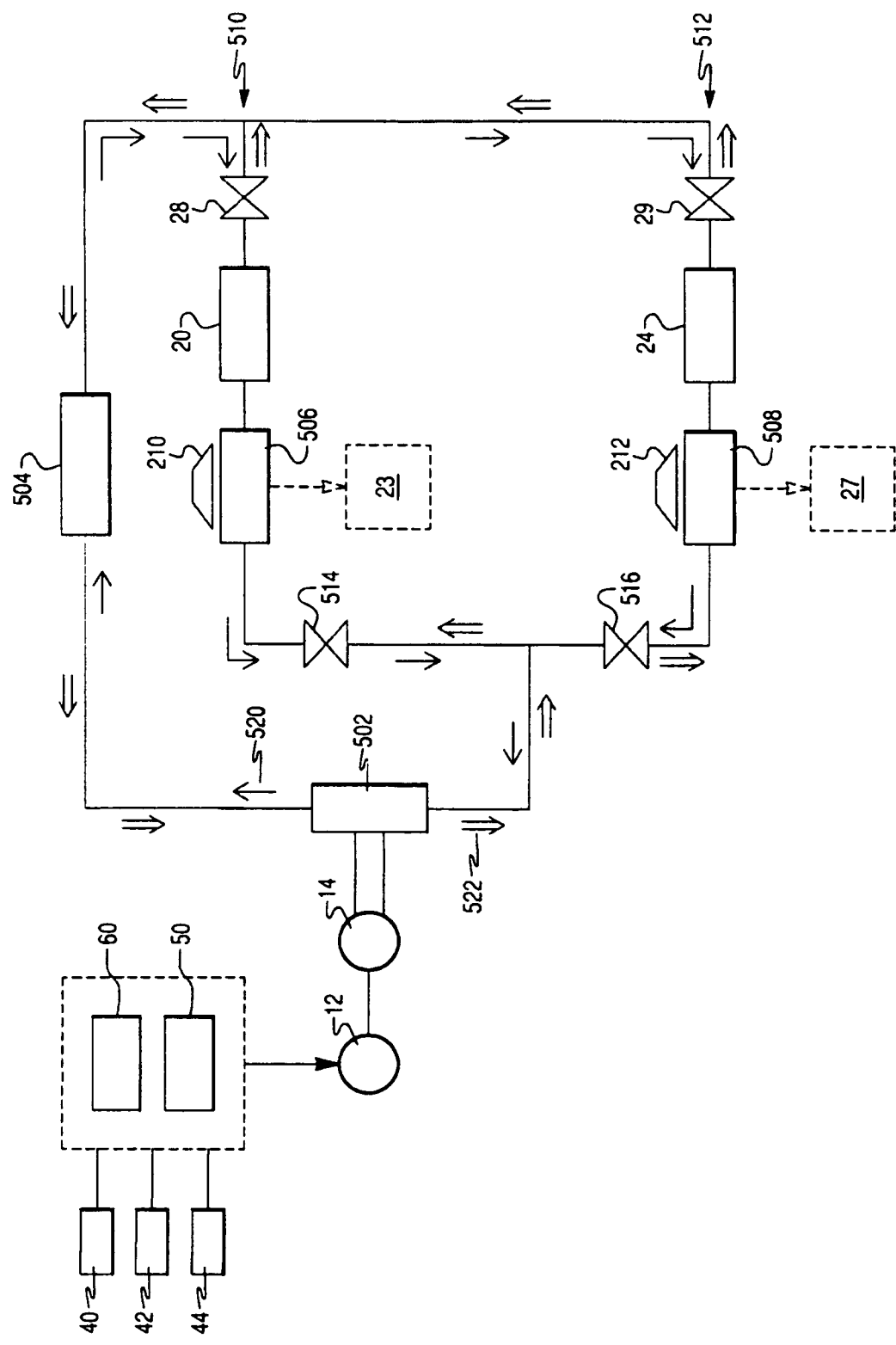


Fig. 5(a)

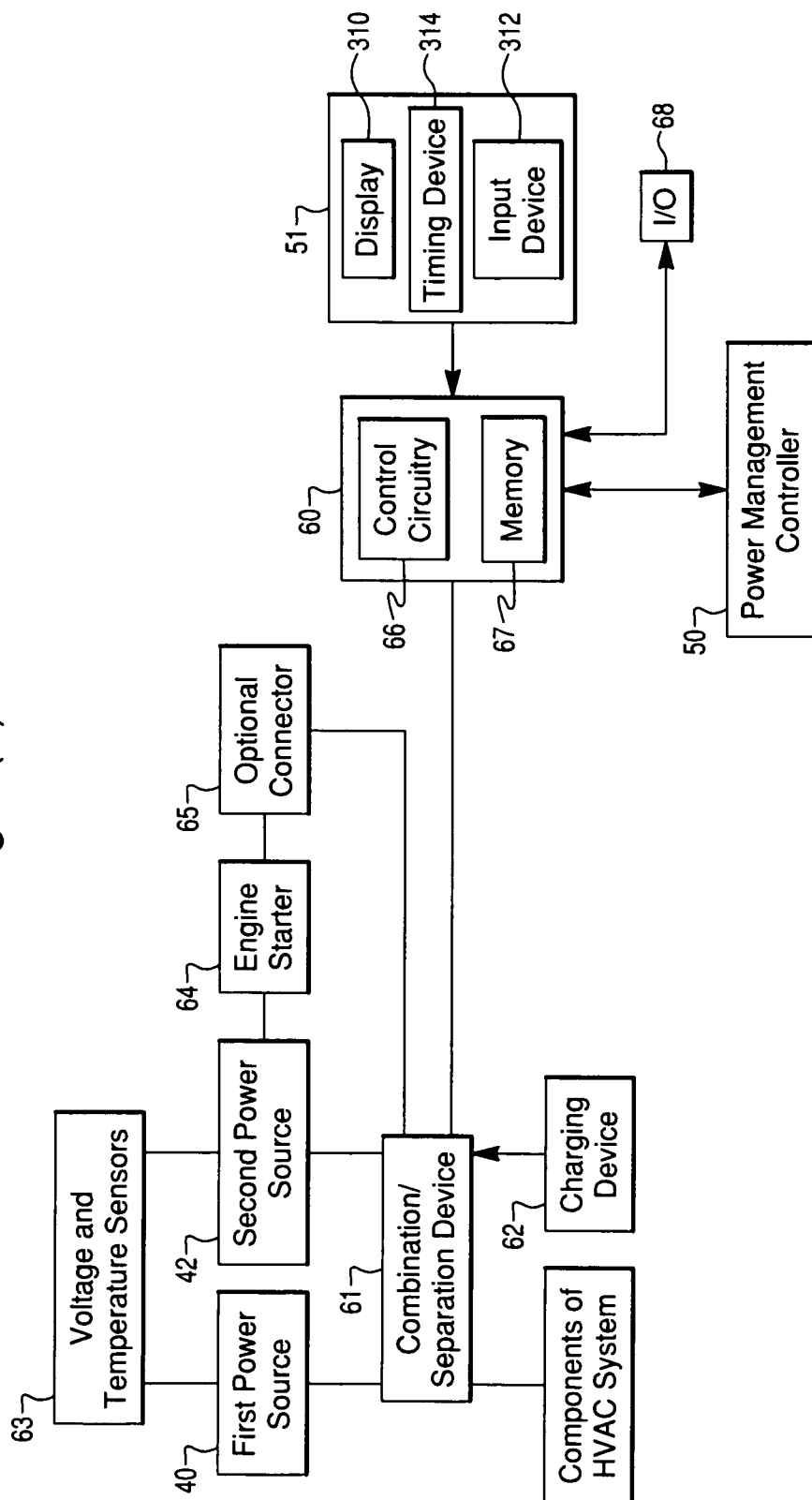


Fig. 5(b)

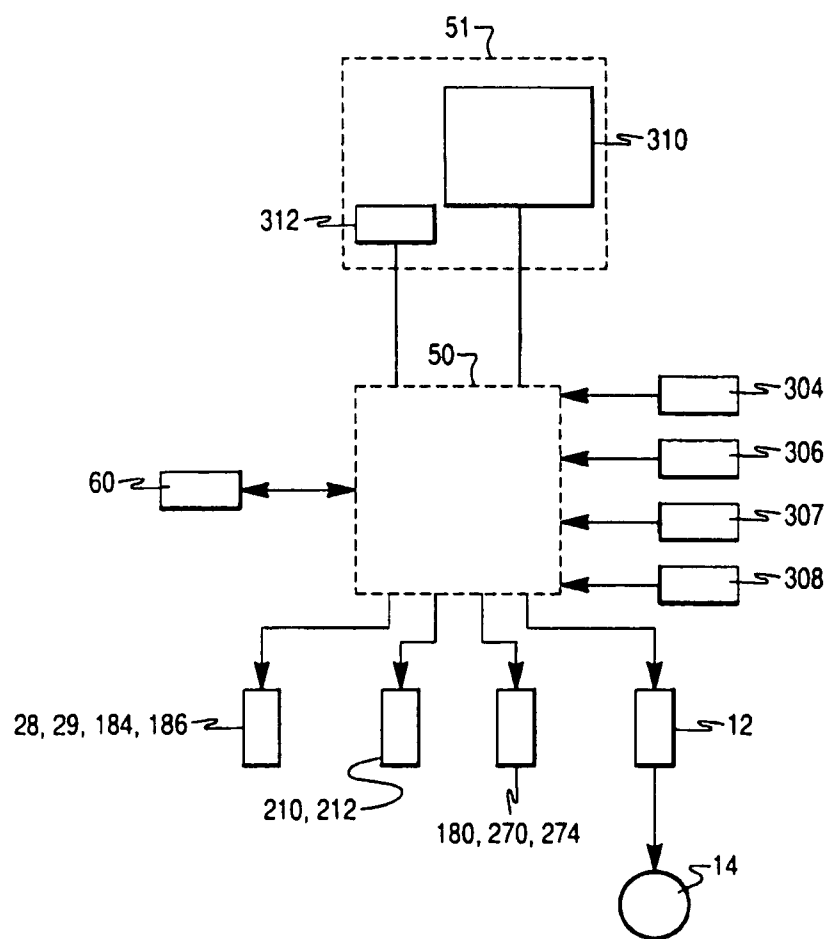




Fig. 6(a)

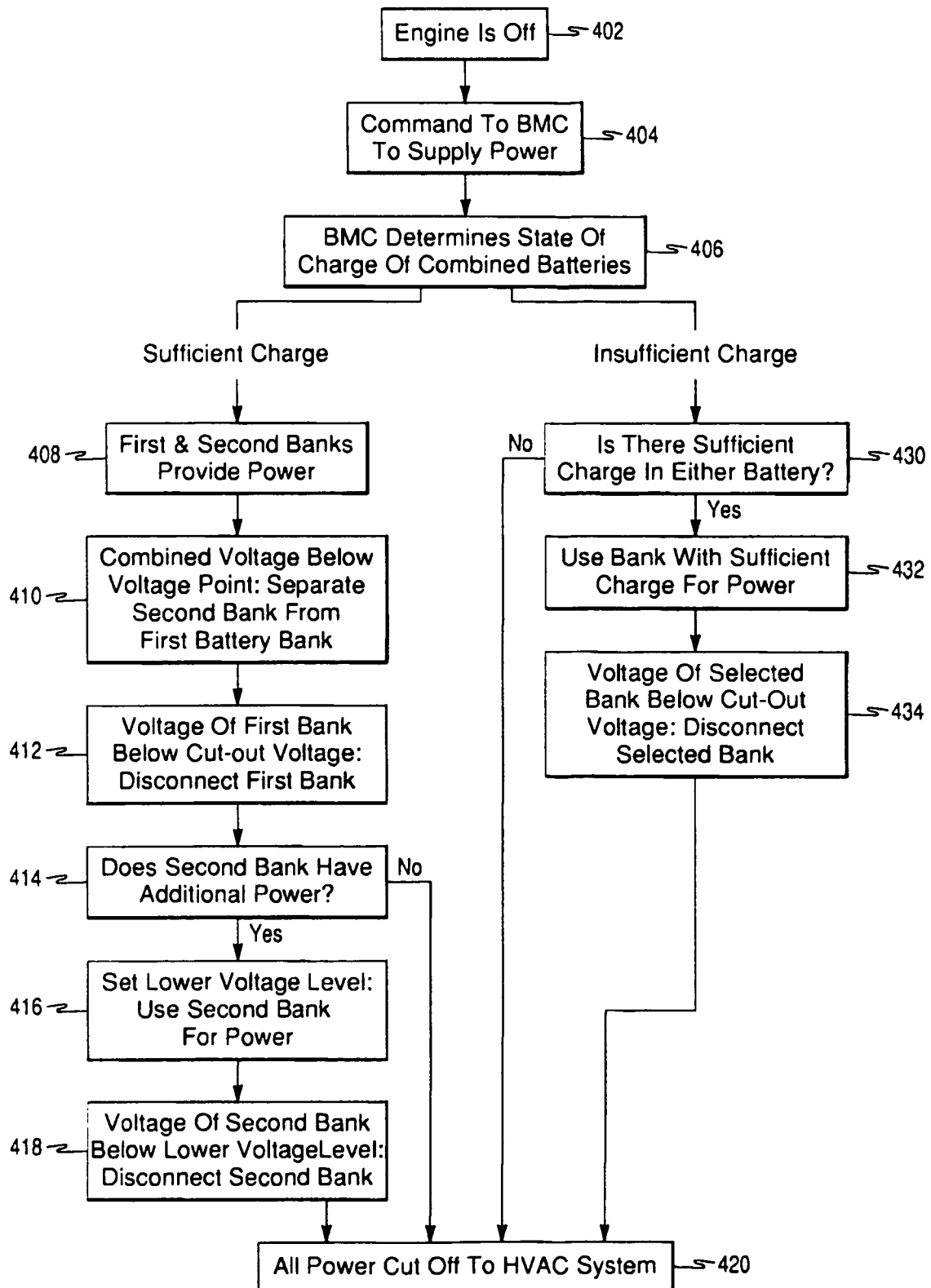


Fig. 6(b)

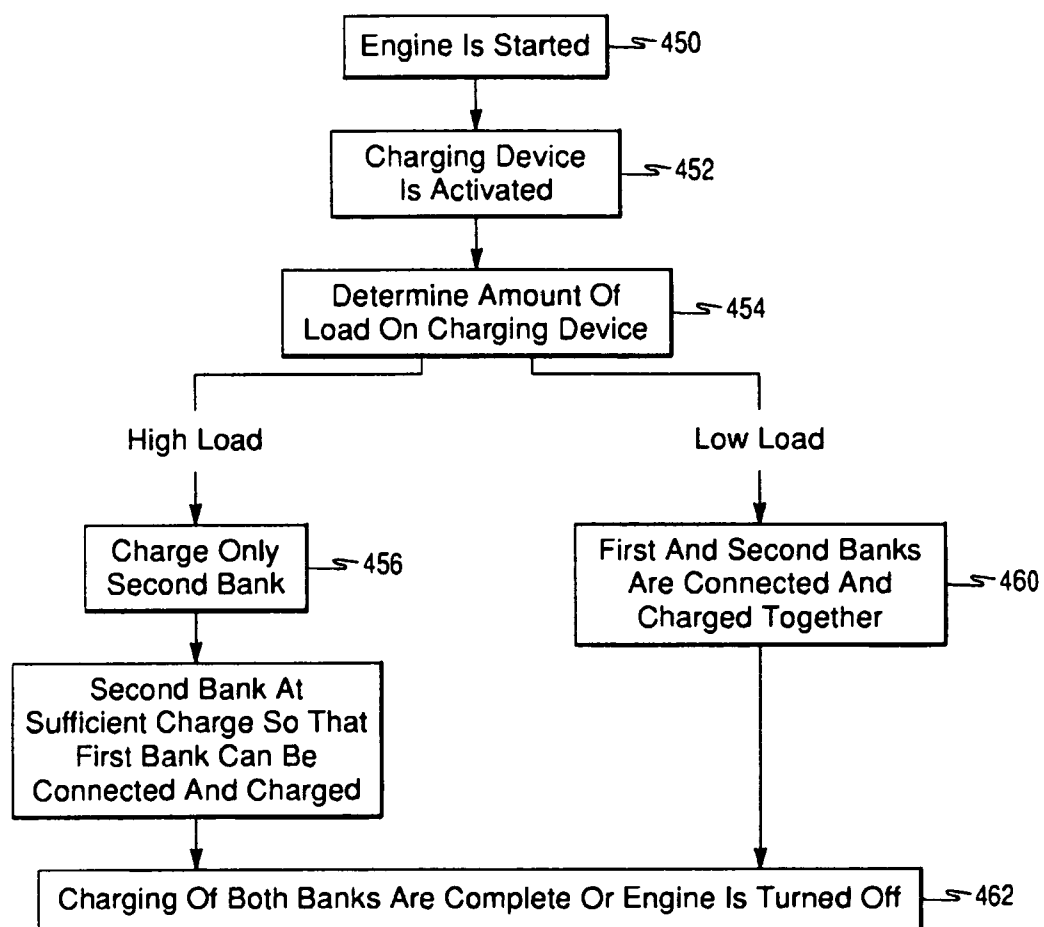


Fig. 7

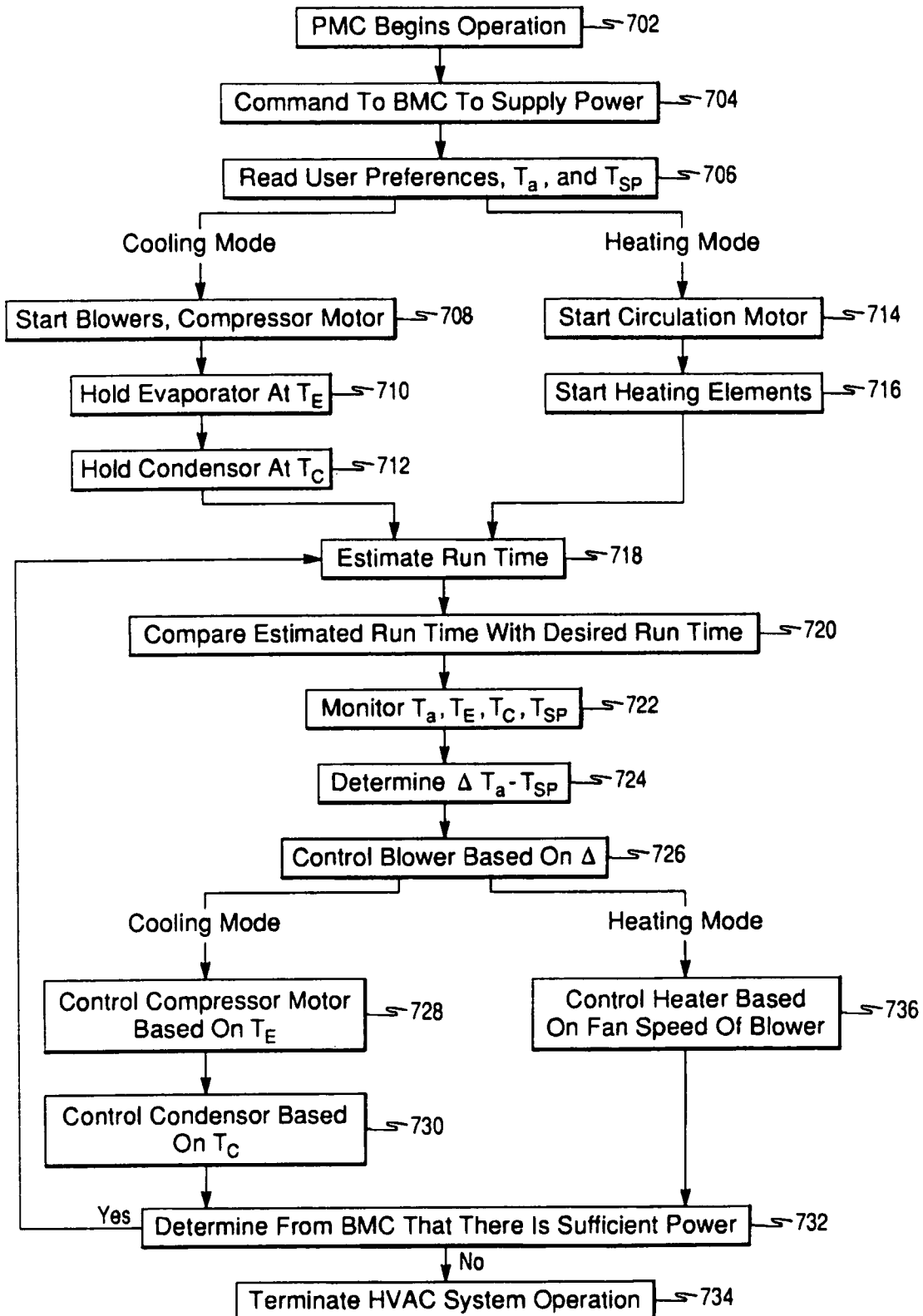


Fig. 8

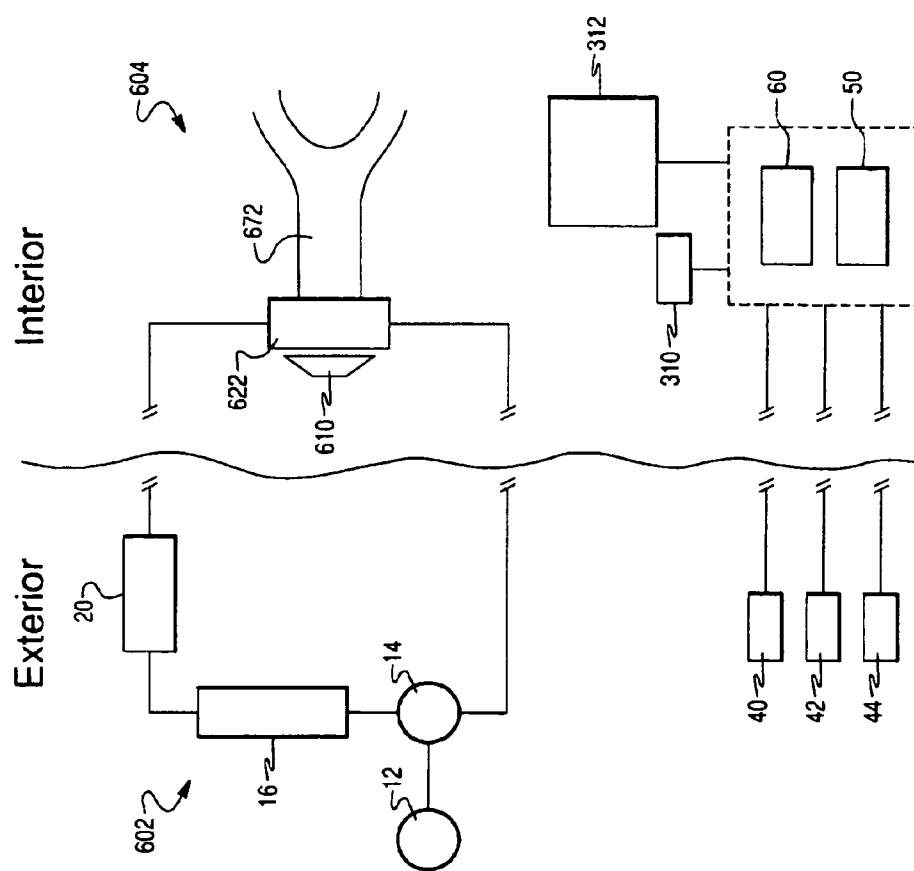


Fig. 9(a)

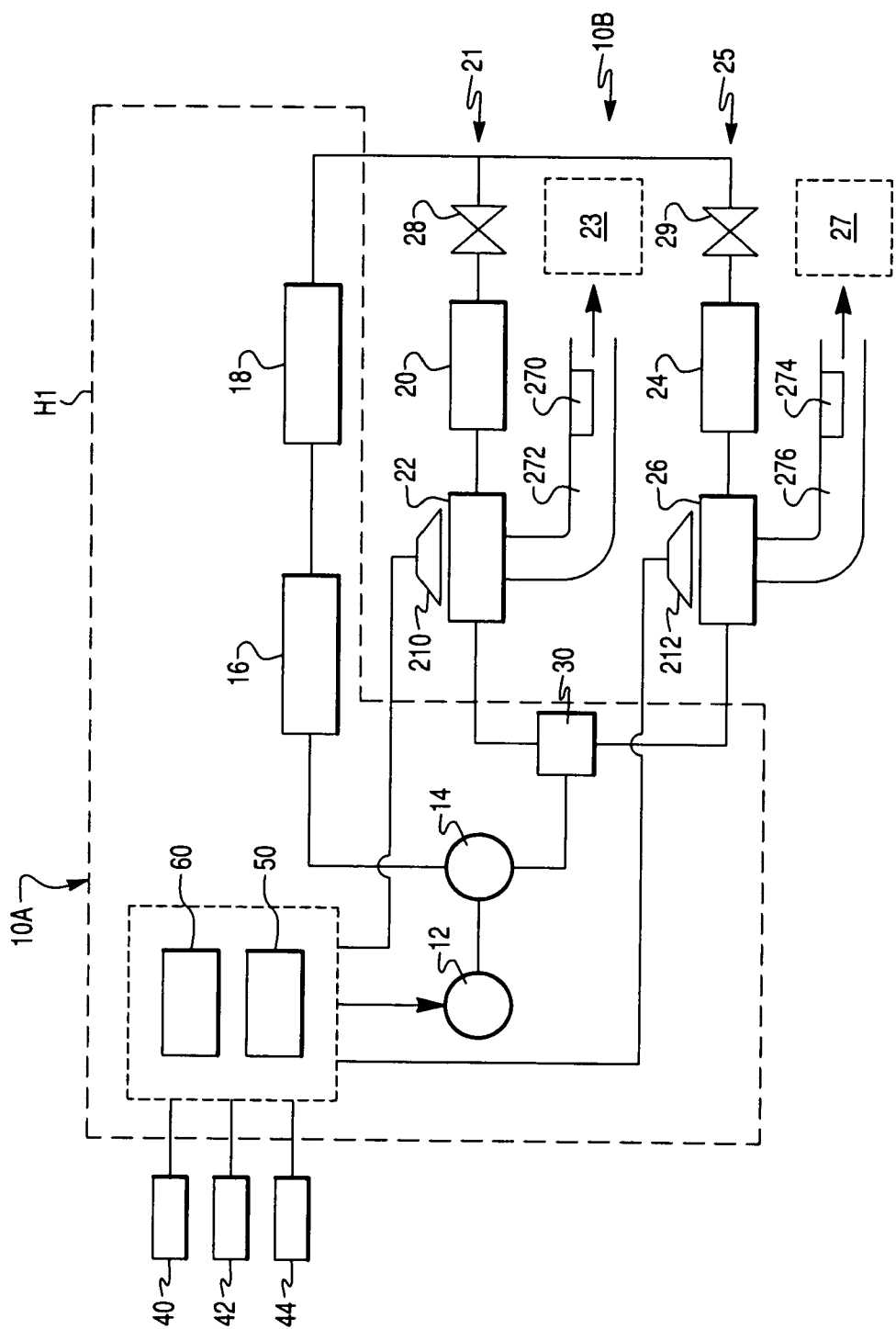


Fig. 9(b)

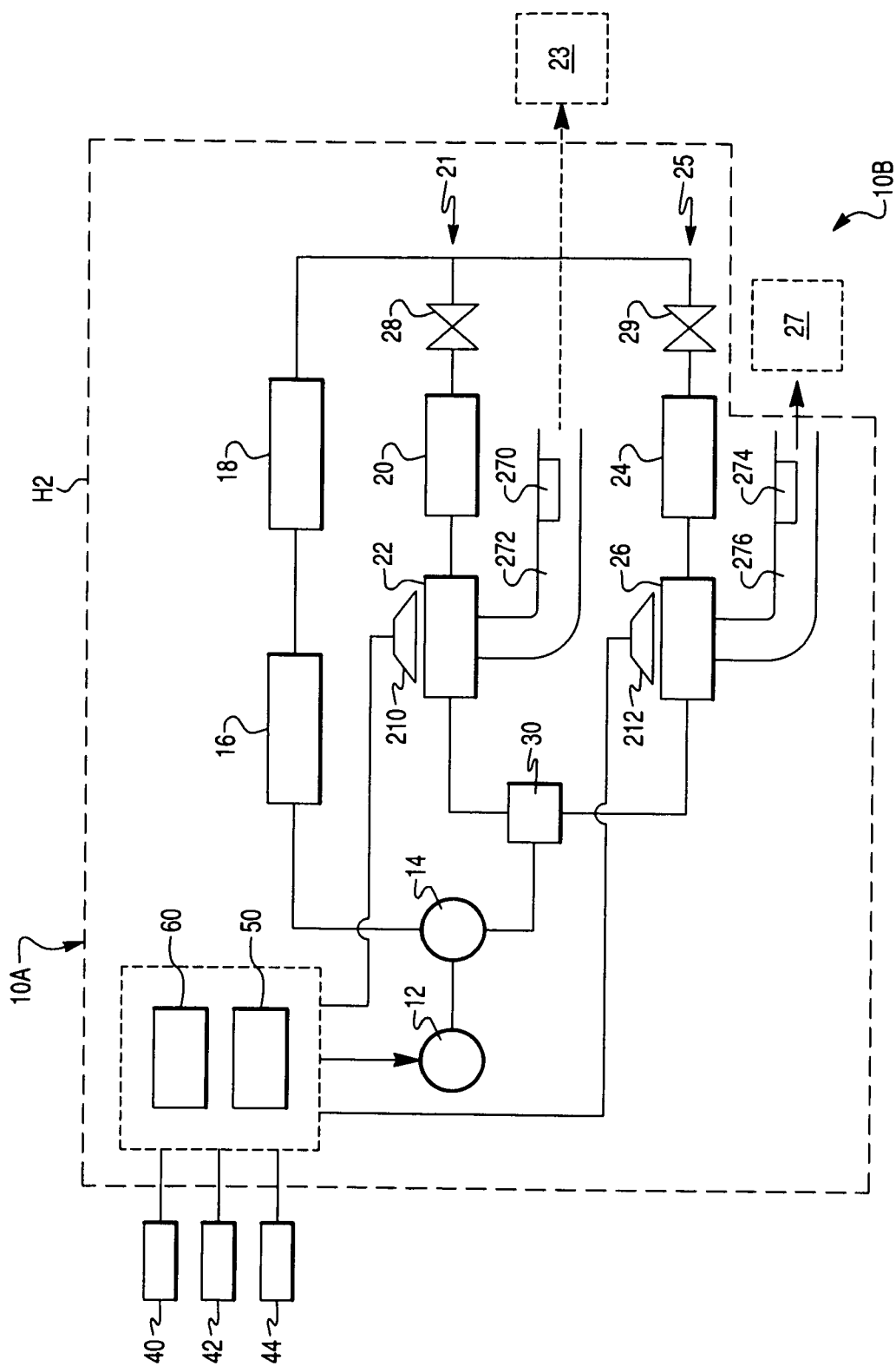
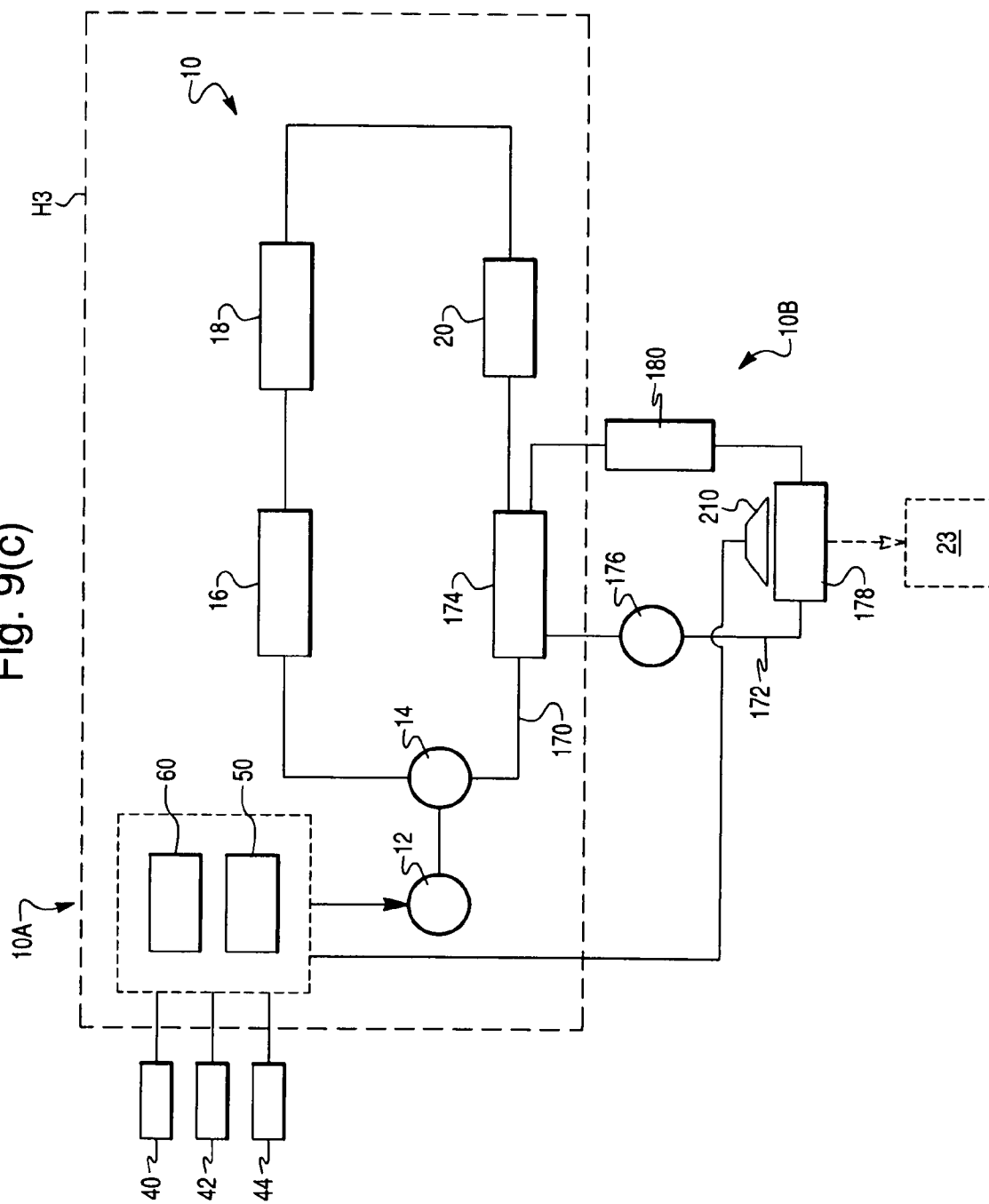
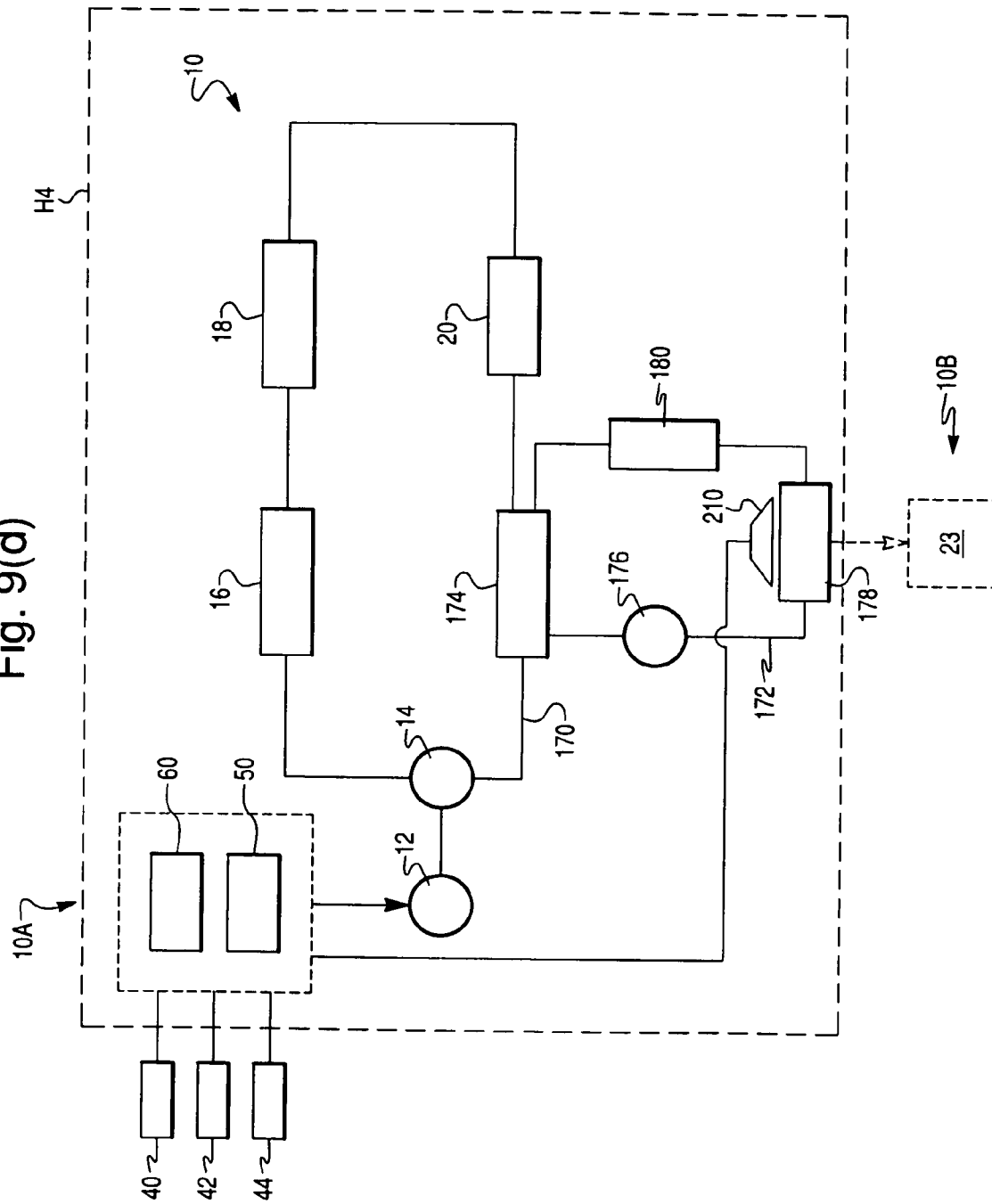


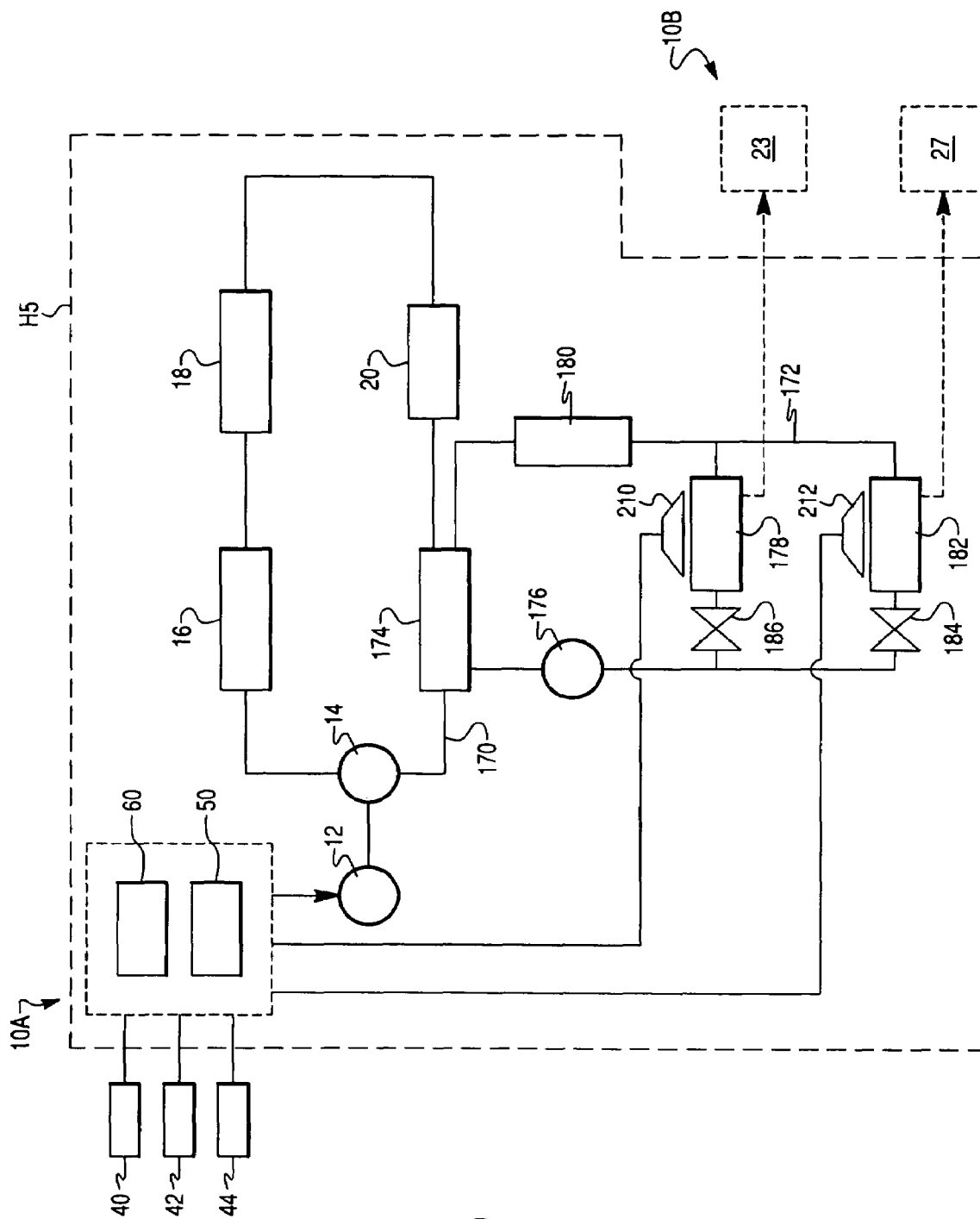
Fig. 9(c)



**Fig. 9(d)**







**Fig. 9(e)**

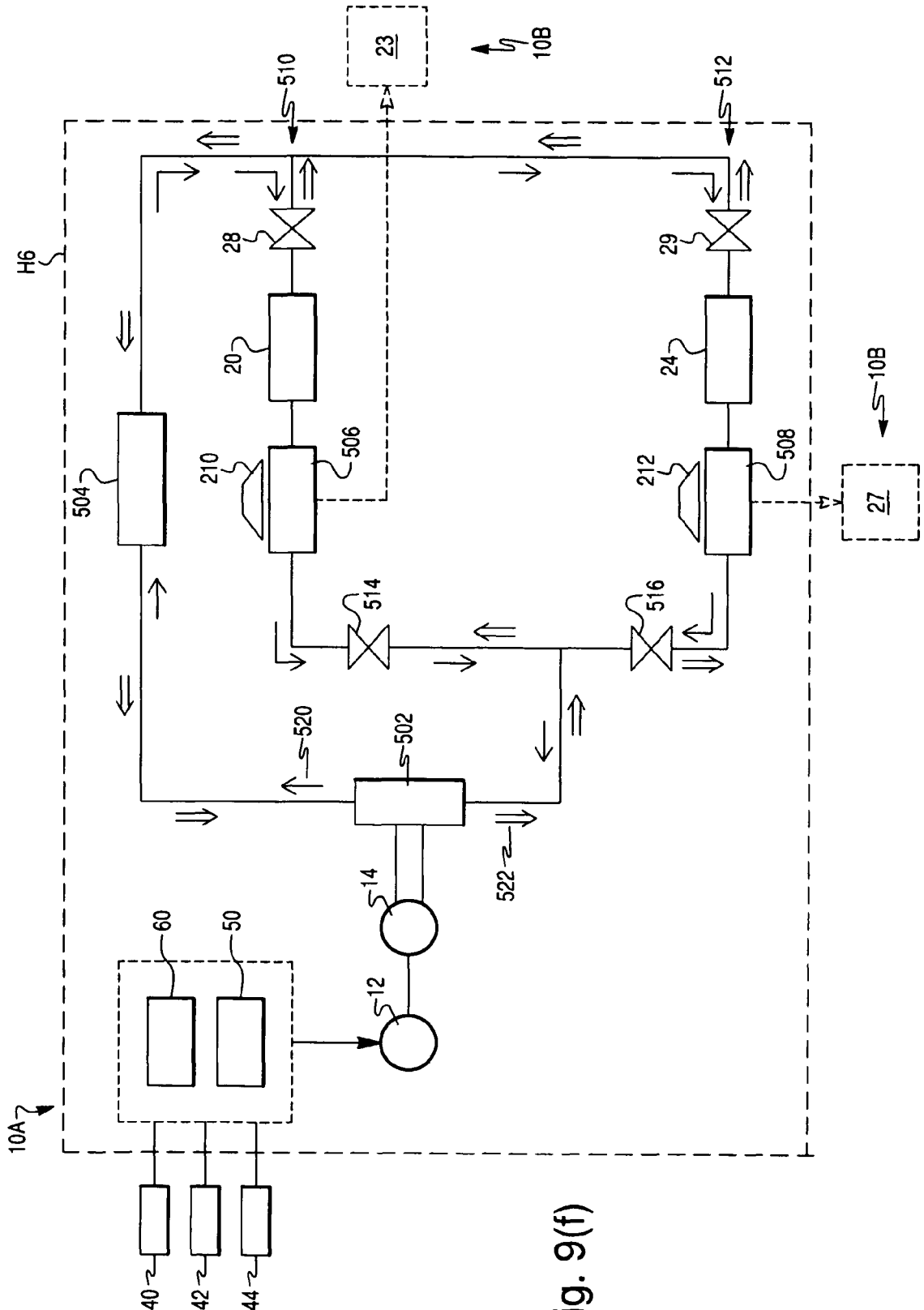


Fig. 9(f)

**Fig. 10**

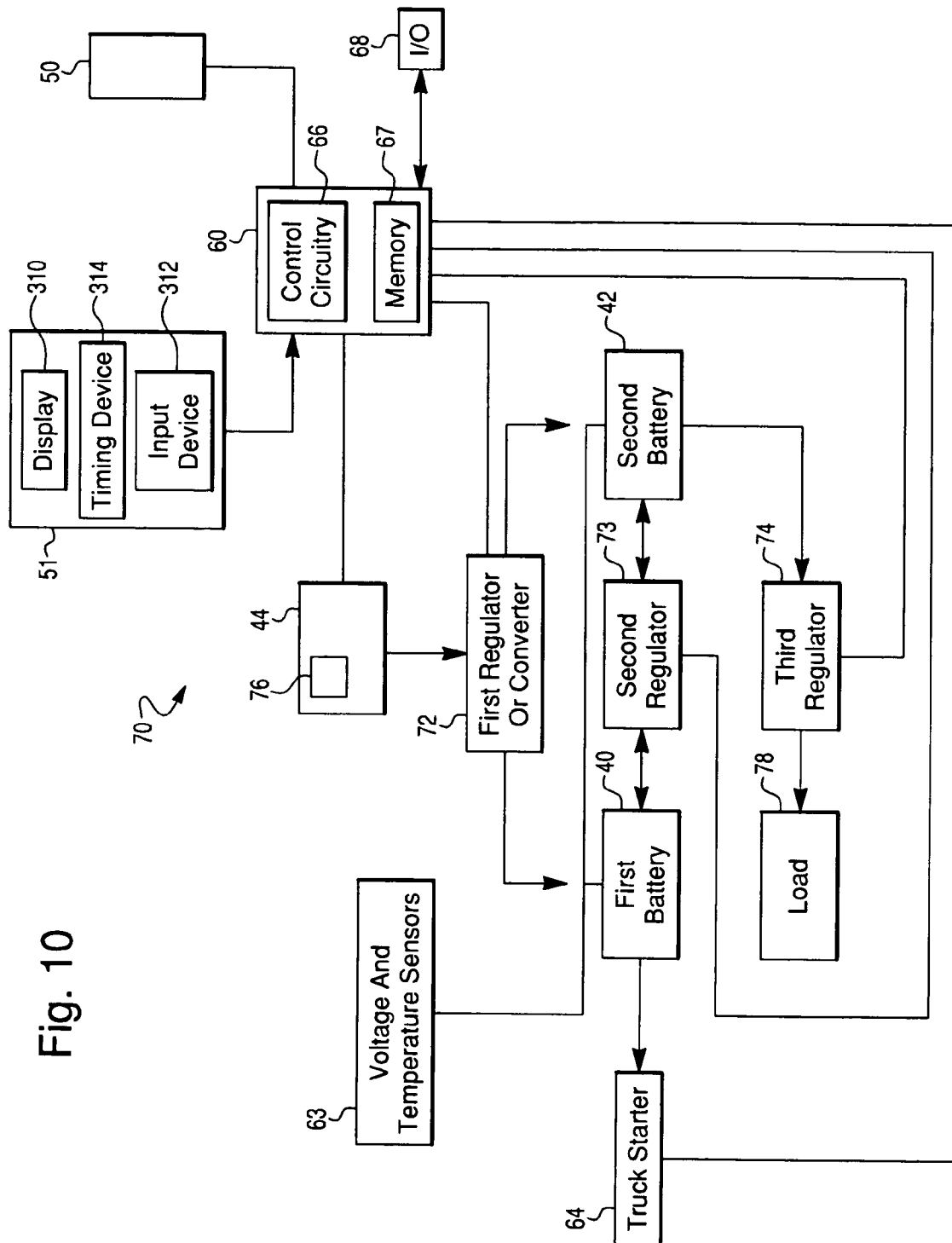


Fig. 11(a)

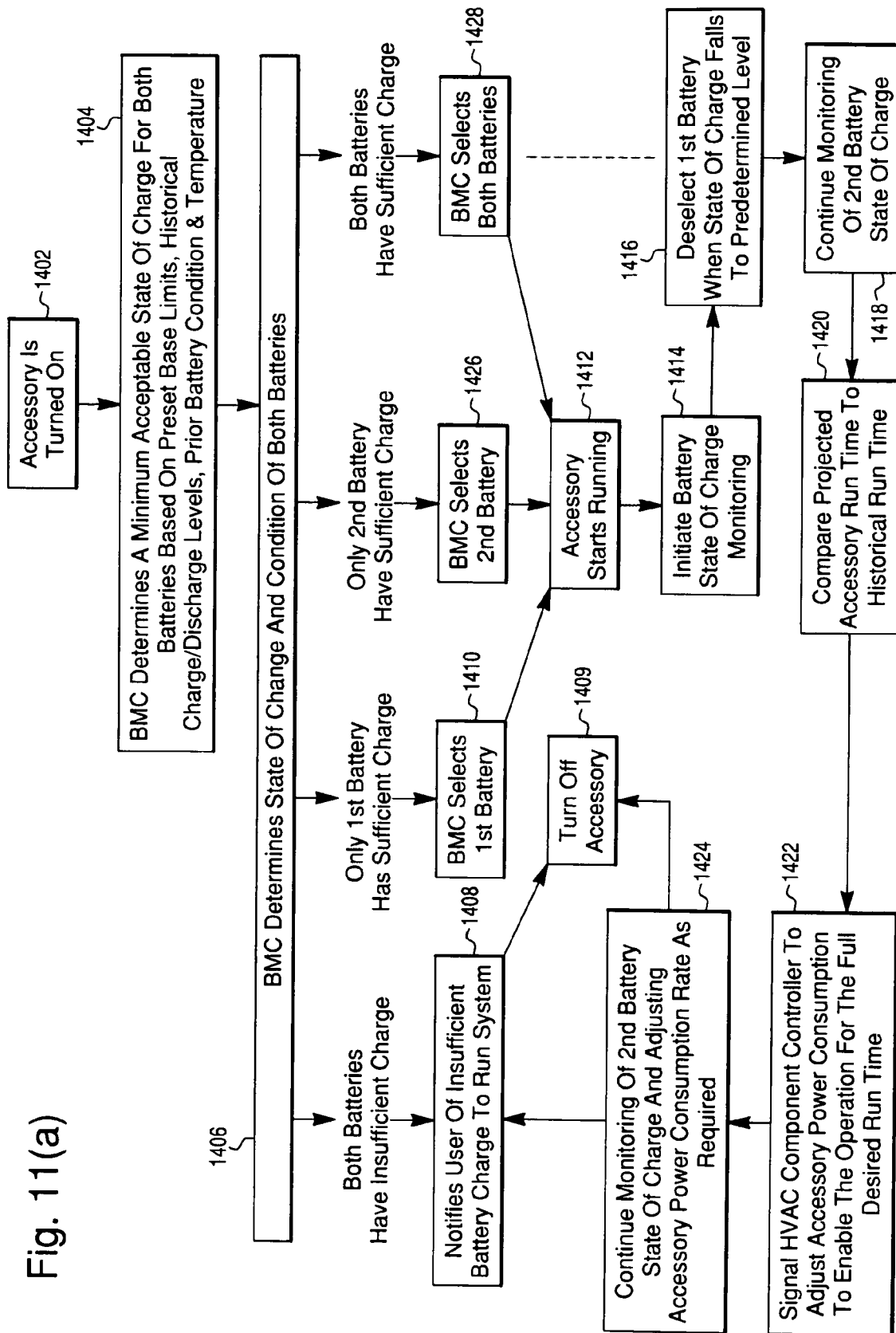


Fig. 11(b)

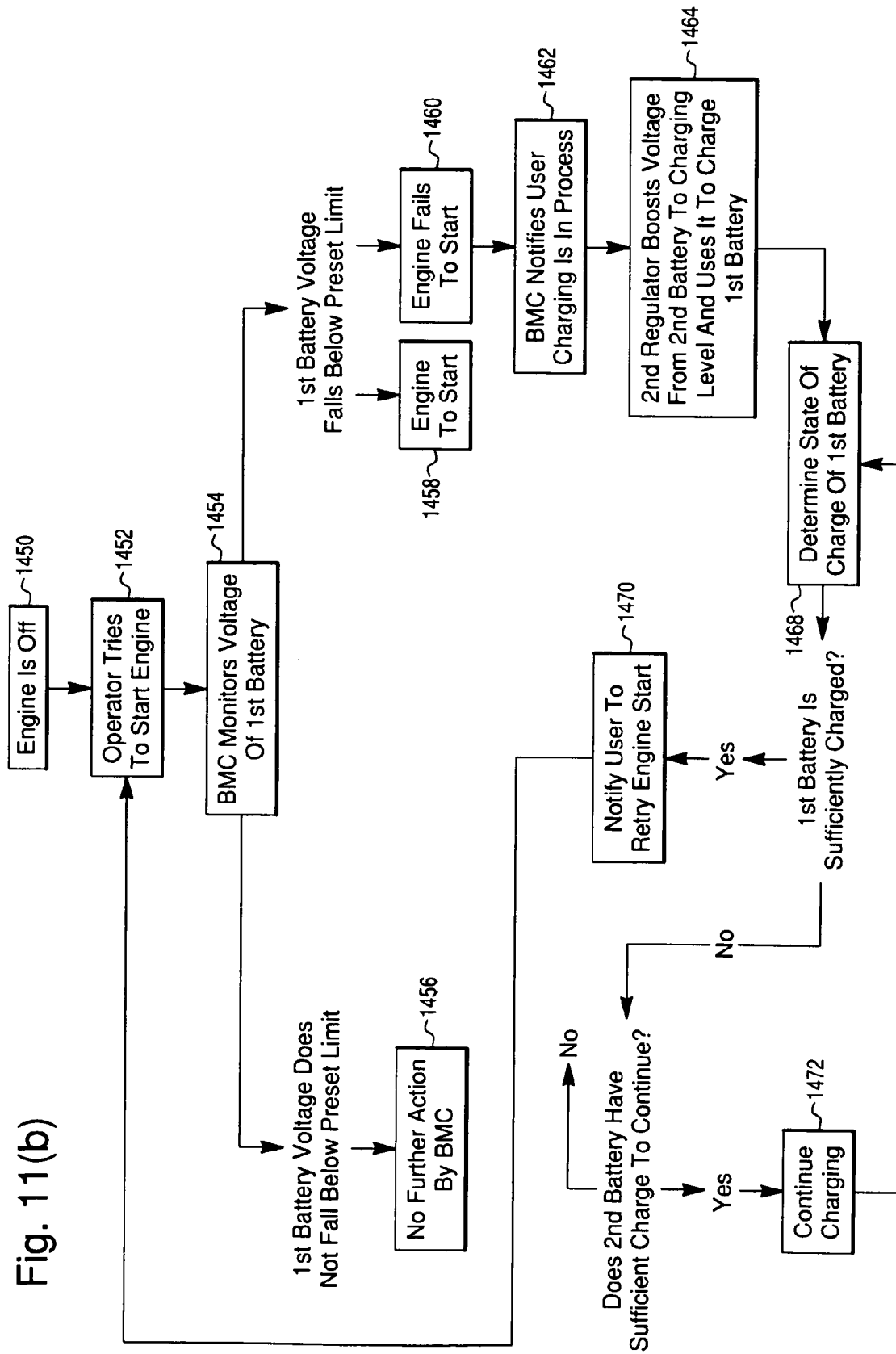


Fig. 11(c)

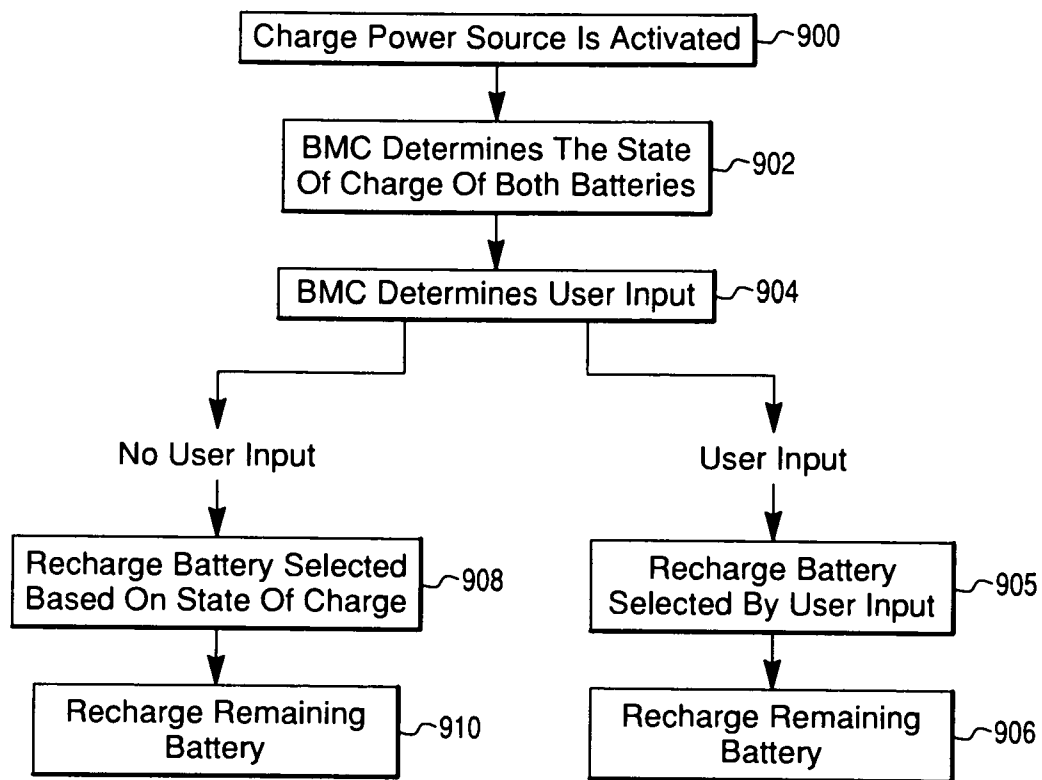


Fig. 12

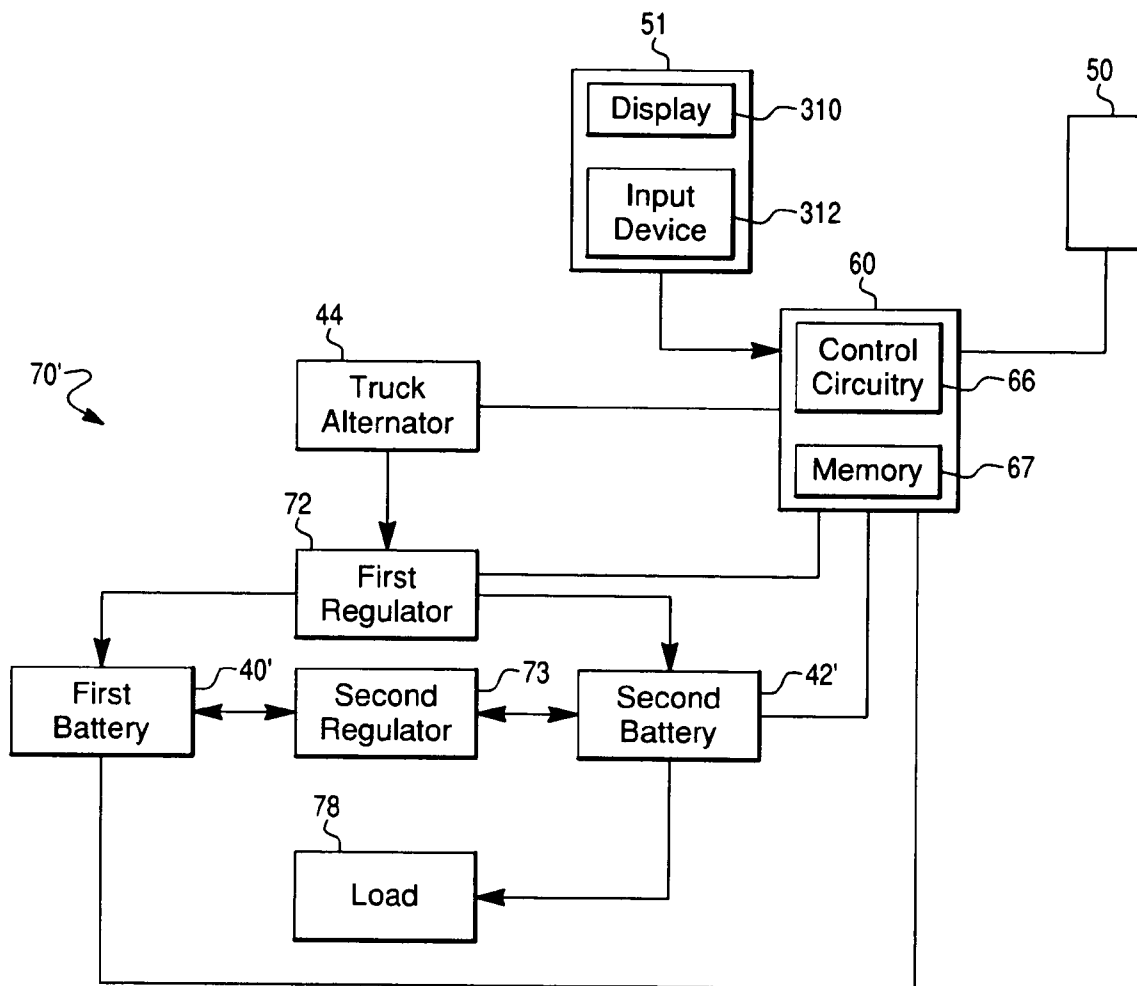


Fig. 13

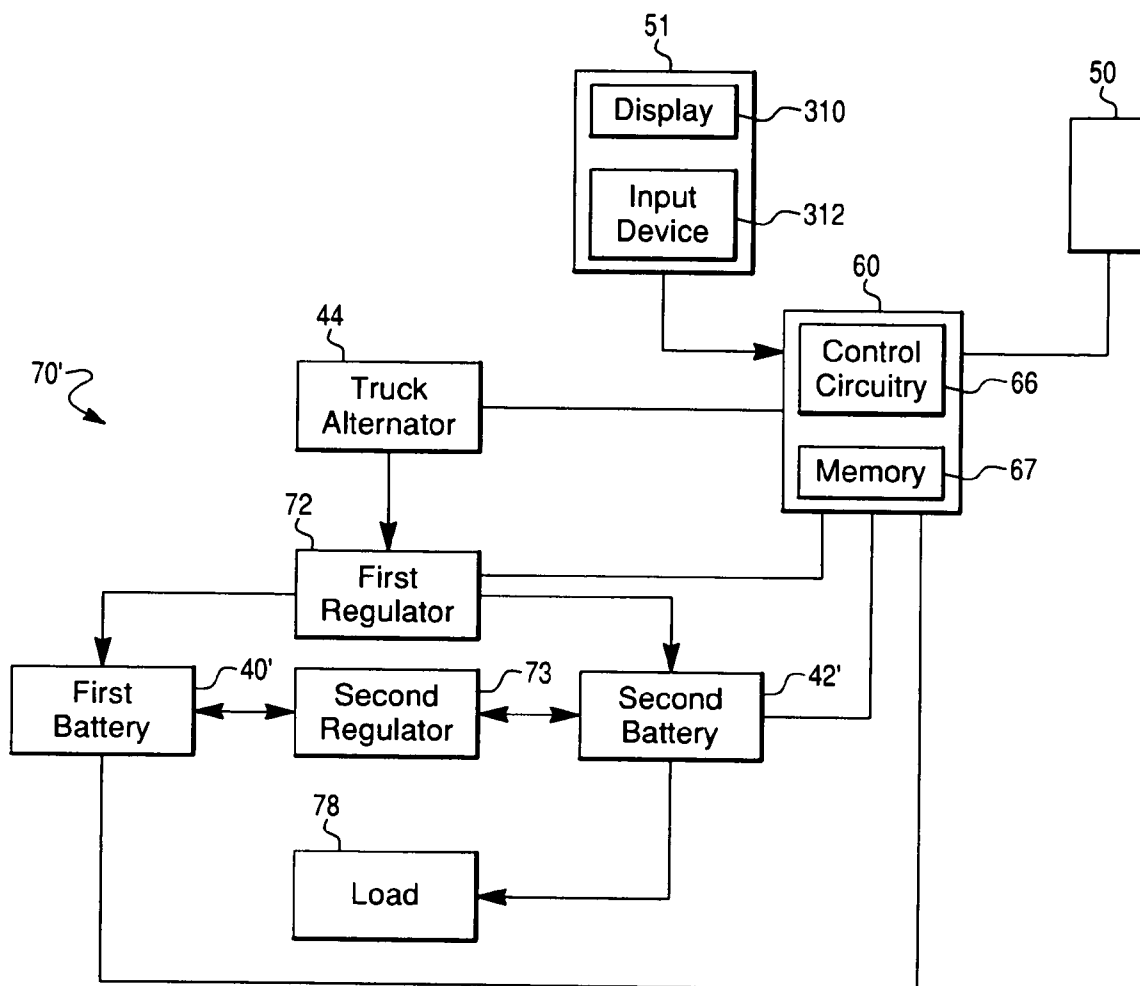




Fig. 14

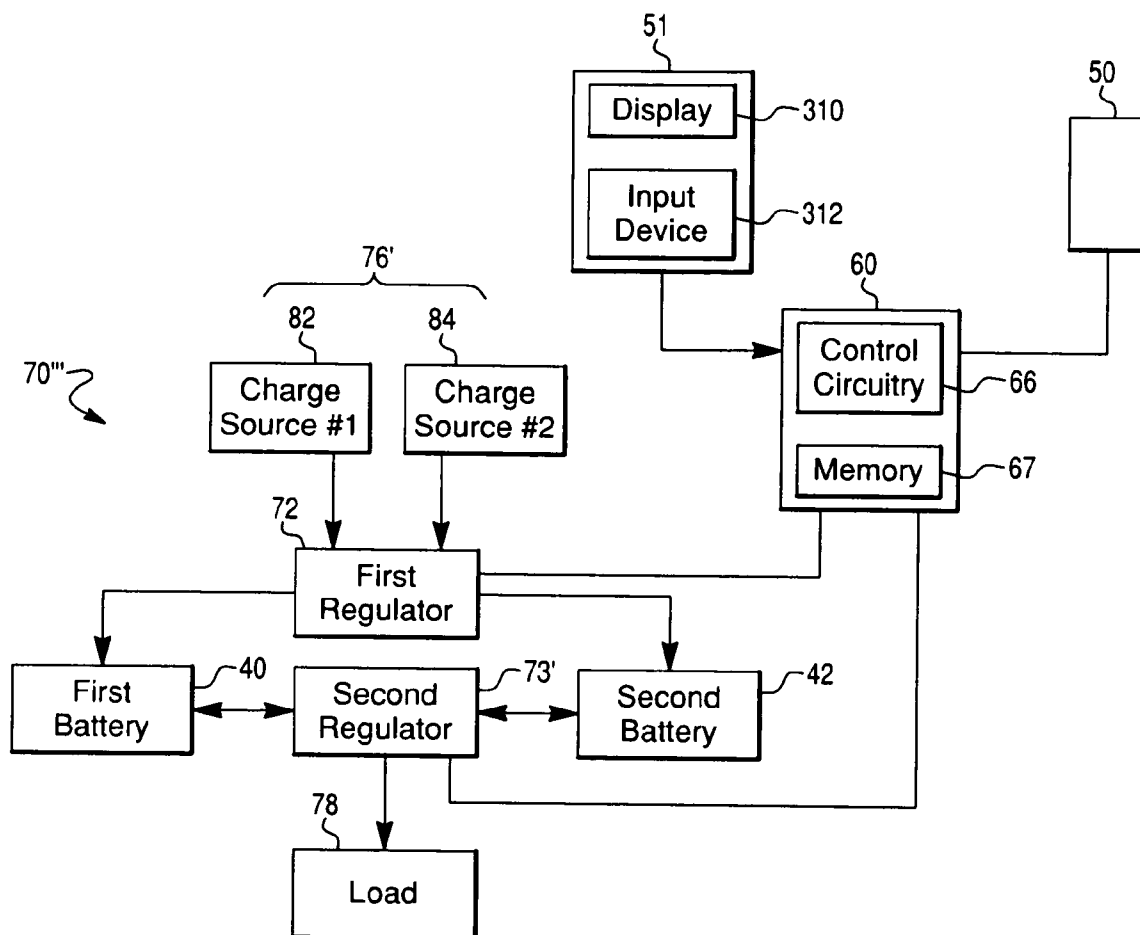


Fig. 15

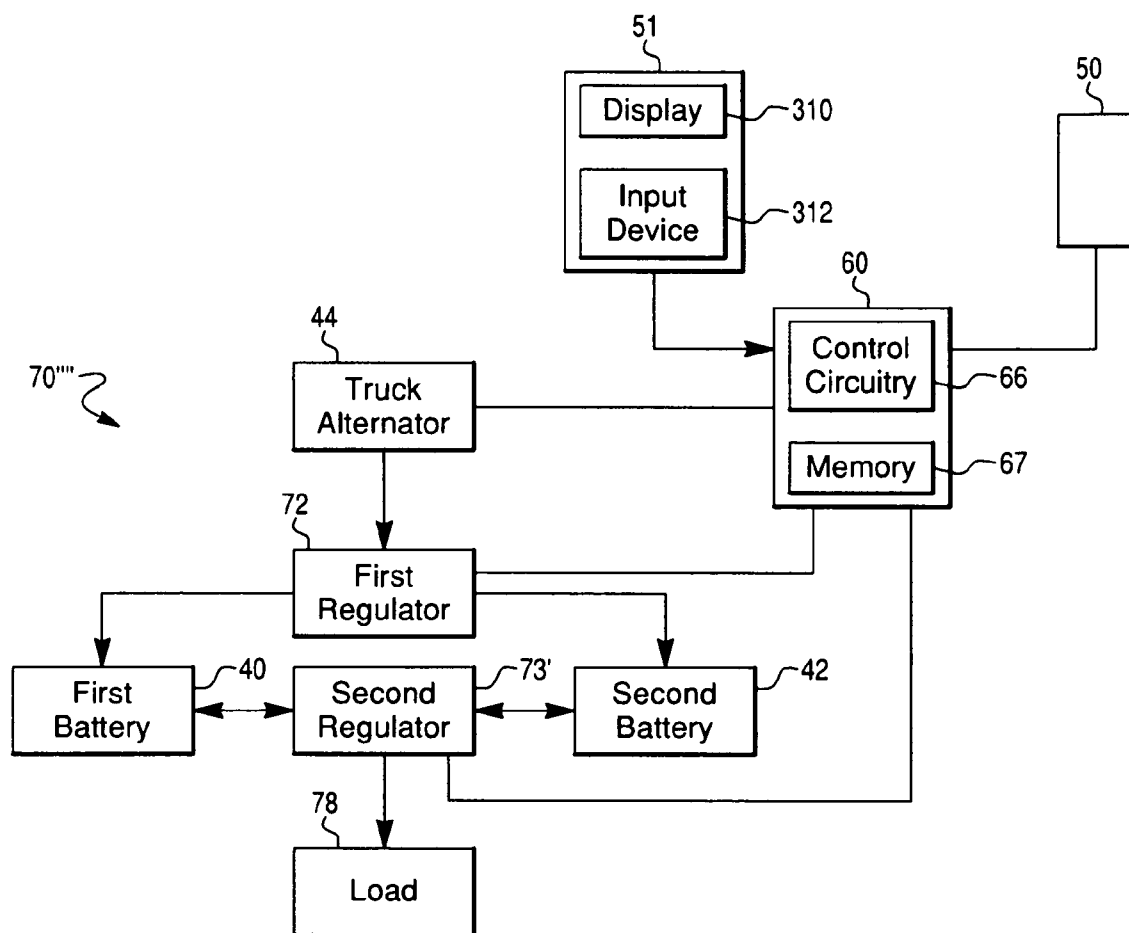


Fig. 16

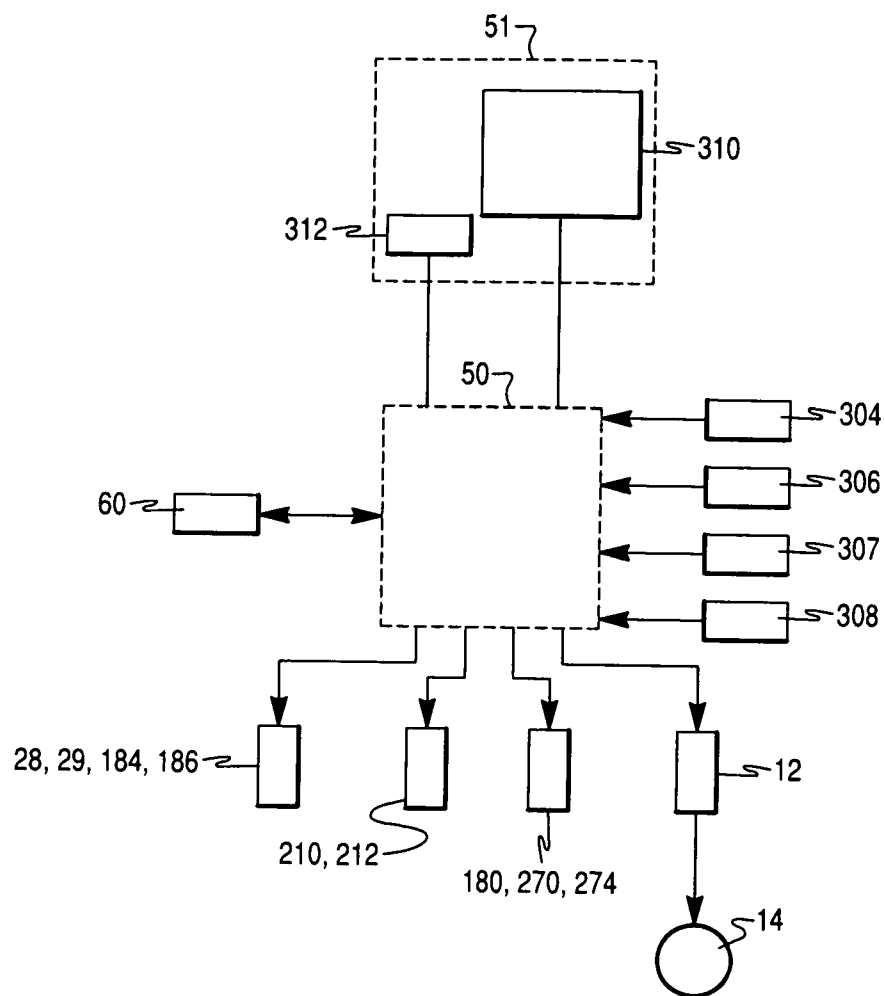


FIG. 17

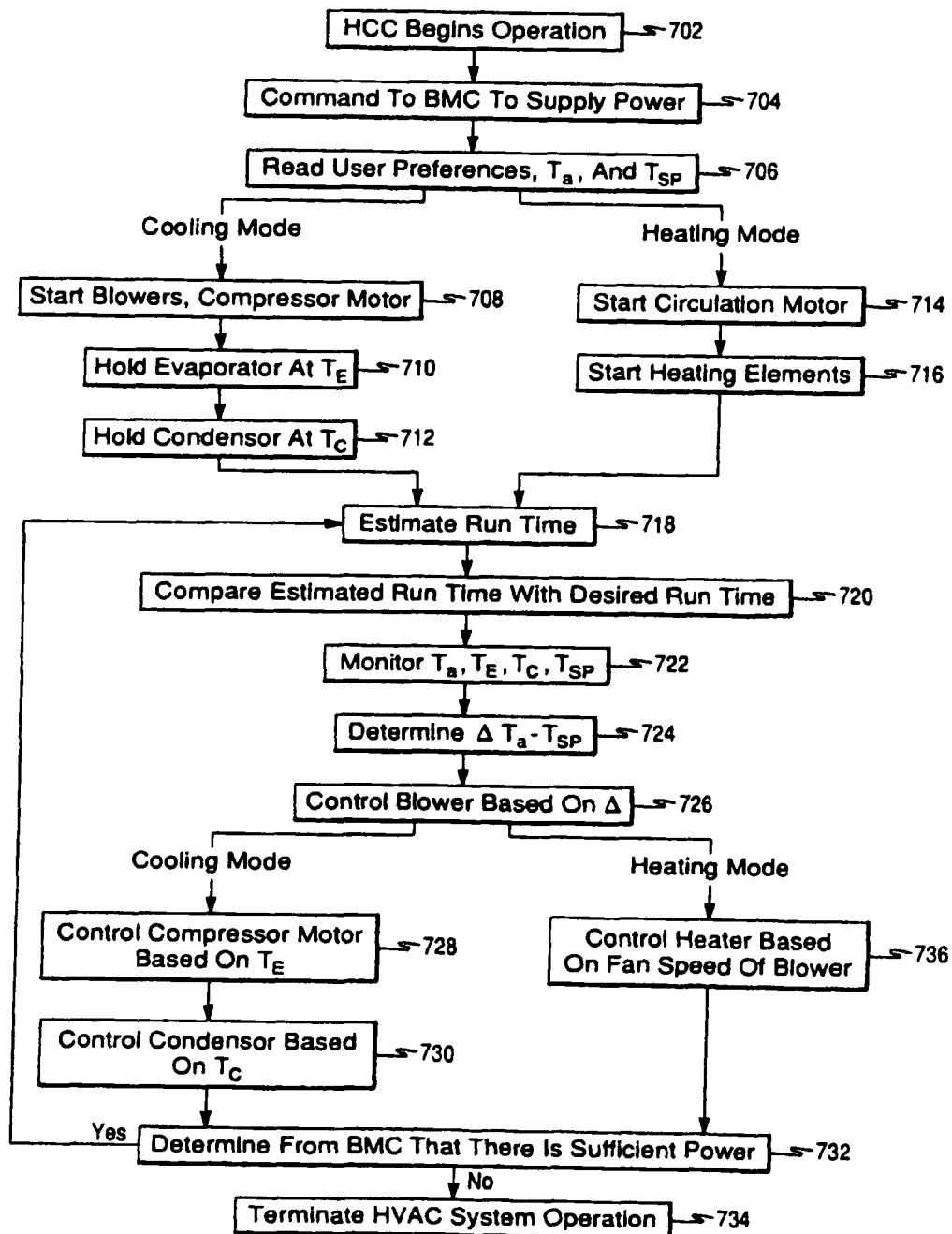


FIG. 18

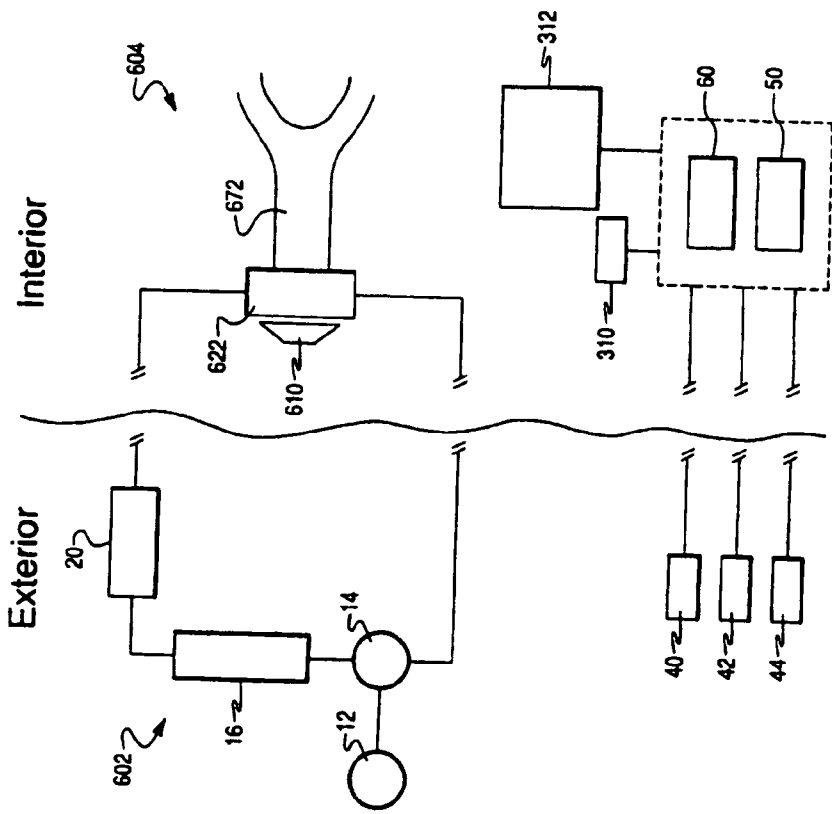


FIG. 19

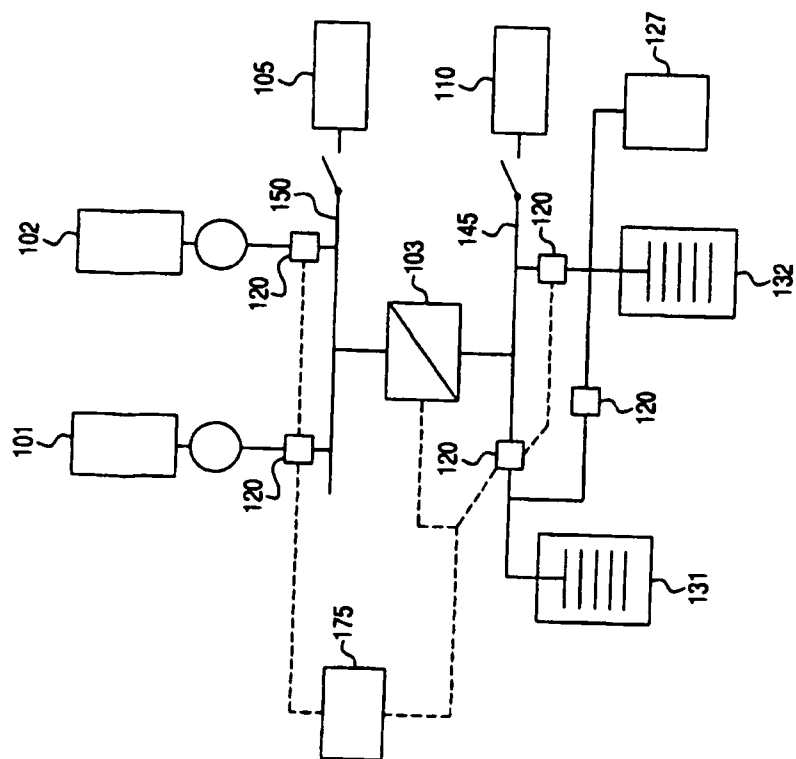
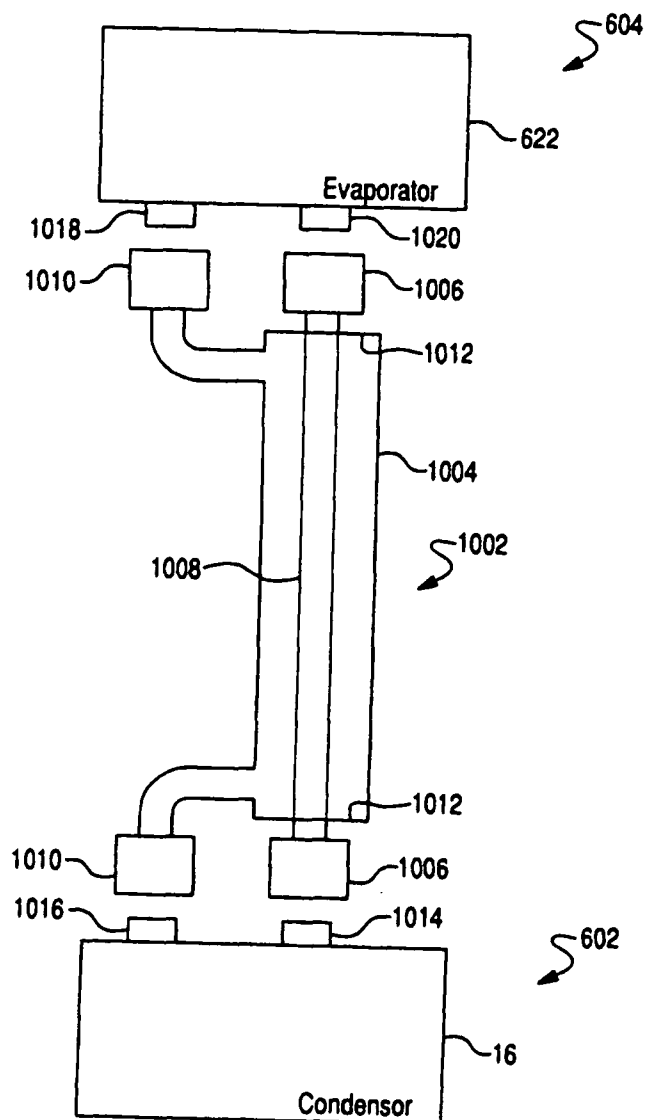
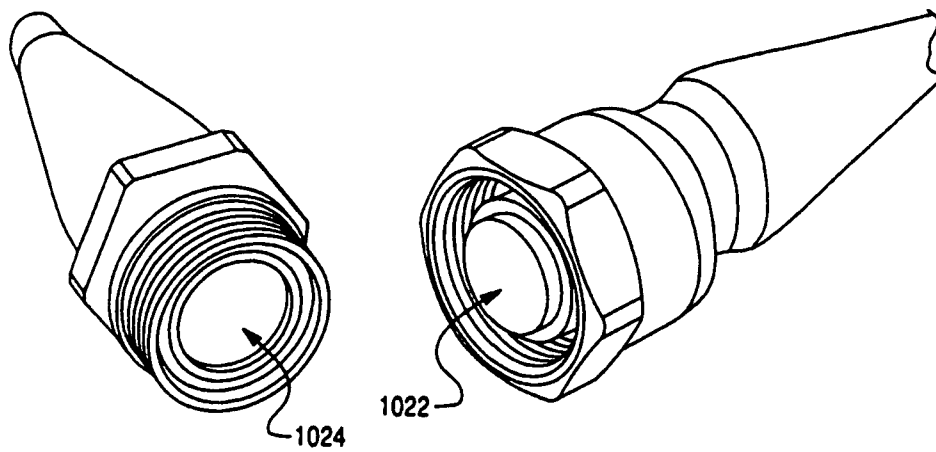


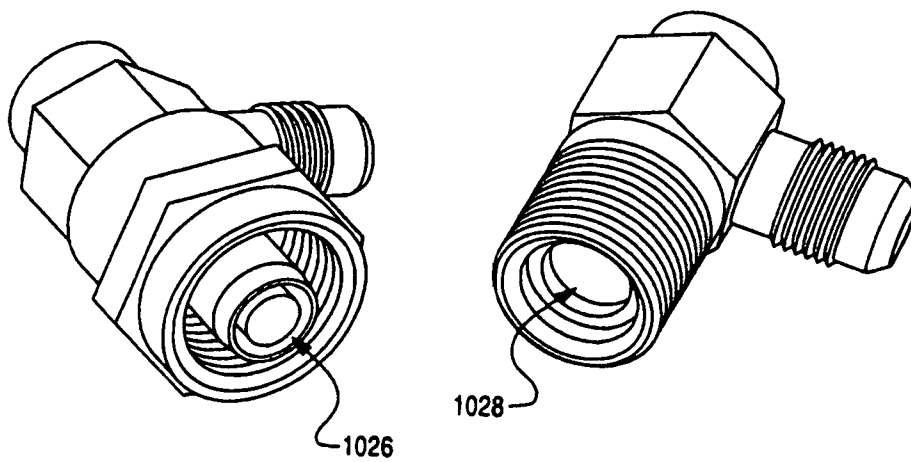
FIG. 20



**Fig. 21(a)**



**Fig. 21(b)**





# HVAC SYSTEM CONTROLLED BY A BATTERY MANAGEMENT SYSTEM

## CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 12/149,095 filed on Apr. 25, 2008, and U.S. patent application Ser. No. 12/320,213 filed on Jan. 21, 2009, which are incorporated by reference herein in their entirety. This application claims priority from U.S. patent application Ser. No. 11/560,160 filed Nov. 15, 2006, which is incorporated herein by reference in its entirety.

## BACKGROUND

The present invention relates to an HVAC system installable in a vehicle and including a battery management controller. The system further comprises a memory storage device that stores data collected by the battery management controller. The data may be transmitted to an input/output device for further analysis.

Truck drivers that move goods across the country may be required to pull over at various times along their journey so as to rest so that they do not become too fatigued. Common places for truck drivers to rest include rest stops, toll plazas, and the like. However, these locations usually do not have any accommodations for the drivers, and as a result they usually remain inside the cab of the truck inside a sleeping compartment. To provide the driver with maximum comfort, the sleeping compartment should be temperature controlled so that the environment in the truck is conducive for the driver to get the rest he or she needs.

Currently, trucks tend to use engine-belt driven compressors for the air conditioning system to circulate and pump refrigerant throughout the vehicle to cool the driving compartments. In addition, an engine-belt driven pump may circulate engine waste heat throughout the driving compartments when heating is required. Unfortunately, these systems have the drawback of not being able to operate when the engine is turned off. As a result, the driver has the choice of either keeping the engine running (which requires additional fuel) so as to run the temperature control system or turning the engine off and not using the air conditioning or heating systems (which may make the driver uncomfortable).

## SUMMARY

An HVAC system to be installed in a vehicle comprises a battery management controller. The battery management controller comprises at least one connection for electrically coupling a first power source with a first voltage; at least one connection for electrically coupling a second power source with a second voltage; and a first memory storage device configured to record data collected by the battery management controller. The battery management controller is configured to run a temperature control system and to supply power to the temperature control system from a combination of the first and second power sources with a combined voltage, and wherein the second power source is disconnected when the combined voltage drops below a predetermined amount.

A power system to be installed in a vehicle comprises a first battery having a first battery voltage and a second battery having a second battery voltage; an electrical power generator configured to charge the first battery; an electrical load powered by at least one of the first battery, the second battery or

the electrical power generator; a converter connected to both the first and second batteries and configured to operate in either a neutral mode or a first battery charging mode or a second battery charging mode, wherein the converter is configured to create a voltage difference between the first and second batteries in the charging modes; a battery management controller configured to monitor the first voltage of the first battery and the second voltage of the second battery and/or to monitor current flow to and from the first and second batteries, wherein the controller controls operation of the converter to operate in either the neutral mode, the first battery charging mode or the second battery charging mode; and a first memory storage device configured to record data collected by the battery management controller. In the second battery charging mode, the converter is configured to adjust the voltage difference between the first battery and the second battery to cause current to flow from the first battery to the second battery to thereby charge the second battery.

An installable HVAC system for a vehicle comprises a housing; a compressor; a motor operatively coupled to the compressor; a condenser in fluid communication with the compressor; a power management controller configured to run the motor with power from a given power source; a battery management controller comprising at least one connection for electrically coupling the given power source with a first voltage and at least one connection for electrically coupling a second power source with a second voltage; and a first memory storage device configured to record data collected by the battery management controller. The compressor, the motor, the condenser, and the power management controller are located within the housing. The housing is configured to attach to an existing HVAC system of the vehicle.

## BRIEF DESCRIPTION OF THE DRAWINGS

The features, aspects and advantages of the present invention will become apparent from the following description, appended claims, and the accompanying exemplary embodiments shown in the drawings, which are briefly described below.

FIG. 1 is a schematic diagram of an HVAC system to be installed in a vehicle.

FIG. 2 is a schematic diagram of an HVAC system according to another exemplary embodiment.

FIG. 3 is a schematic diagram of an alternative configuration of the HVAC system of FIG. 2.

FIG. 4 is a schematic diagram of an HVAC system according to another exemplary embodiment.

FIGS. 5(a) and 5(b) are schematic diagrams of the battery management controller and the power management controller, respectively, according to an embodiment of the present invention.

FIGS. 6(a) and 6(b) are flow charts showing the operation of the battery management controller during the discharging and recharging of the power sources, respectively, according to an embodiment of the present invention.

FIG. 7 is a flow chart showing the operation of the power management controller according to an embodiment of the present invention.

FIG. 8 is a schematic diagram of an HVAC system to be installed in a vehicle according to an embodiment of the present invention.

FIGS. 9(a)-9(f) are schematic diagrams of different embodiments of an installable HVAC system to be installed in a vehicle.

FIG. 10 is a schematic diagram of a power system according to an embodiment of the present invention.

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FIG. 11(a) is flow chart showing the operation of the power system during an accessory run mode.

FIG. 11(b) is flow chart showing the operation of the power system during an engine start mode.

FIG. 11(c) is a flow chart showing the operation of the power system during a recharging mode.

FIG. 12 shows a schematic diagram of a power system according to another embodiment of the present invention.

FIG. 13 shows a schematic diagram of a power system according to another embodiment of the present invention.

FIG. 14 shows a schematic diagram of a power system according to another embodiment of the present invention.

FIG. 15 shows a schematic diagram of a power system according to another embodiment of the present invention.

FIG. 16 is a schematic diagram of a HVAC component controller.

FIG. 17 is a flow chart showing the operation of the HVAC component controller.

FIG. 18 is a schematic diagram of an HVAC system to be installed in a vehicle.

FIG. 19 is a power generation system including a battery management controller.

FIG. 20 is a liquid phase cooler connecting the interior and exterior subsystems of FIG. 13.

FIG. 21(a) is a perspective frontal view of low-loss quick connectors for connecting the liquid phase cooler according to an embodiment of the present invention.

FIG. 21(b) is a perspective frontal view of one-time quick connectors for connecting the liquid phase cooler according to an embodiment of the present invention.

### DETAILED DESCRIPTION

Hereinafter, various embodiments of the present invention will be described in detail with reference to the drawings.

FIG. 1 is a schematic diagram of an HVAC system to be installed in a vehicle according to an embodiment of the present invention. The HVAC system 10 may comprise a motor 12, a compressor 14, circulation blowers 210 and 212, a power management controller 50 (sometimes referred to as an HVAC component controller 50), and a battery management controller 60. The motor may be operatively coupled to the compressor 14. The compressor 14 is a stepless continuously variable speed compressor, which is driven by the motor 12. The compressor 14 circulates refrigerant through the condenser 16 to an optional refrigerant receiver and dryer 18. From the refrigerant receiver and dryer 18, the refrigerant then passes to either a first cooling path 21 that cools the driving compartment 23 or a second cooling path 25 that cools the sleeping compartment 27 of the vehicle. As to the first cooling path 21, the refrigerant passes through a refrigerant metering device 20 and an evaporator 22. The refrigerant metering device 20 may or may not be an expansion device, such as a thermostatic expansion valve, a pressure control expansion valve, a capillary tube, or the like, used in the conventional way. In one arrangement, the refrigerant metering device 20 is a metering device feeding refrigerant into the flooded evaporator 22 with no expansion taking place at or near the valve 20, and thus merely meters in liquid refrigerant at a rate sufficient to maintain the correct liquid level in the evaporator. Air is blown over the evaporator 22 by the circulation blower 210. After the air is cooled by the evaporator 22, the air proceeds through an air duct 272 towards the driving compartment 23 of the vehicle.

A second cooling path 25 runs parallel to the first cooling path 21 in which the refrigerant is provided through a refrigerant metering device 24 and an evaporator 26. Air is blown

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over the evaporator 26 by a circulation blower 212. After the air is cooled by the evaporator 26, the air proceeds through an air duct 276 towards the sleeping compartment 27 of the vehicle. The evaporator 26 of the second cooling path 25 may be smaller than the evaporator 22 of the first cooling path 21 because the sleeping compartment 27 is typically smaller than the driving compartment 23.

The two coolant loops may be selectable through the use of valves 28 and 29. The inclusion of such valves permits the driving compartment 23, the sleeping compartment 27, or both compartments to be air conditioned at a particular time. The valves 28 and 29 may be controlled through the power management controller 50 (to be discussed below). Once the refrigerant passes through the evaporator 22 and/or 26, the refrigerant then passes through an optional refrigerant accumulator 30 before being returned to the compressor 14 to restart the process.

The motor 12 may be any suitable motor. For example, the motor 12 may be a brushless DC motor that is commutated by a square or trapezoidal wave form. In another example, the motor 12 may be a synchronous permanent magnet motor that is commutated with a sine wave. When the motor is driven by a sine wave, additional benefits may be obtained, such as better drive efficiency, better cooling and quieter operation.

By using a variable speed compressor 14 driven by a brushless DC or a synchronous permanent magnet motor 12, the vehicle's HVAC system may be operated when the engine is turned on or when the engine is turned off. The variable speed compressor 14 also may permit the HVAC system 10 to operate at a lower capacity during the engine off operation to conserve the amount of stored energy available for usage by the system 10. The control for this operation is provided by a power management controller 50 that monitors various system parameters while a battery management controller 60 monitors the availability and status of the power sources on the vehicle. The available power sources can include a first power source 40, a second power source 42, and/or the vehicle's main electrical power generation system 44. Additionally, the available power sources and battery management controller 60 may be part of a power system 70, as seen in FIG. 10 and discussed further below.

In a similar manner, the circulation blowers 210 and 212 may also have stepless continuously variable speeds such that the circulation blowers may operate at a lower capacity during the engine off operation to conserve the amount of stored energy available for usage by the HVAC system 10. The control for this operation is also provided by the power management controller 50.

The battery management controller 60 is configured such that the vehicle's HVAC system 10 is capable of being powered by the vehicle's main electrical power generation system 44, which is available while the vehicle's engine is operating. When the vehicle's engine is off, the HVAC system 10 may be powered with a first power source 40 and/or a second power source 42 depending on the power levels of the power sources (as will be described later). In one embodiment, the first power source 40 may be the vehicle's one or more starter batteries while the second power source 42 may be one or more auxiliary deep-cycle batteries. In another embodiment, one of the first and second power sources may be an external source of AC power connected to the system through an external connection.

In the HVAC system 10, the motor driven compressor 14 may have the ability to modulate its output from full capacity to low capacity. This ability to modulate allows the use of a single HVAC system that may be used for both high output for the time periods that the engine is operating, and low output

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during the time periods when the engine is turned off so as to continue to cool or heat the driving and/or sleeping compartments. The coordination of this modulation is provided by the power management controller 50, which reduces the speed of the compressor when the engine is turned off. This modulation extends the duration of the heating and cooling operations because the charge of the available power sources is expended more slowly. That is, with a reduced speed of the compressor, the electric power demand is reduced as well.

Another aspect of FIG. 1 is a heating mode of operation in which there is an air heater in each air duct that leads to the vehicle compartments. For example, the air heater 270 is disposed in the air duct 272 which leads to the driving compartment 23. The air heater 274 is disposed in the air duct 276 which leads to the sleeping compartment 27. The air heaters 270 and 274 may be any heater known in the art, such as an electric resistance-type heater. The advantage of using an electric resistance-type heater is that such a heater allows the heating function to be completed without relying on the engine or additional fuel by merely relying on the circulation blowers and the heaters, which are powered by the first and/or second power sources or the vehicle electrical power generation system. In a preferred embodiment, instead of the air ducts 272 and 276, the air heaters 270 and 274 may be placed within the same enclosures as the circulation blowers 210 and 212 but still in the path of the gas stream which enters the vehicle and/or sleeping compartments. If the air heaters are in the same enclosures as the circulation blowers, there may be a reduction in the complexity of the installation.

To operate in the heating mode, the power management controller 50 does not operate the compressor 14 but merely operates the circulation blower 210 and the air heater 270 to provide the necessary heating to the driving compartment and/or the circulation blower 212 and the air heater 274 to provide the necessary heating to the sleeping compartment. This configuration provides additional power consumption savings and allows for a longer operating duration in the heating mode. In the cooling mode of operation, the air heaters 270 and 274 are simply not activated. If temperature control is desired, the power management controller 50 may preferably provide pulse width modulation control (PWM) of power to the air heaters 270 and 274. Alternatively, temperature control may be performed by a control door known in the art (not shown) placed in each duct (if provided) to control the flow of air (which may or may not be cooled by the evaporators 22 and/or 26) passing over the air heaters 270 and/or 274 to regulate the temperature of the air flowing into their respective vehicle compartments.

The embodiment of FIG. 1 may include alternative configurations. For example, the first or second cooling path may be eliminated such that there is only one expansion device, one evaporator, one blower, and no accumulator 30. With this configuration only one vehicle compartment may be temperature controlled. Alternatively, ducting may be used to channel the temperature controlled air into separate channels in which a first channel goes to the driving compartment and a second channel goes to the sleeping compartment. In this embodiment, a control door or the like may be used to channel the temperature controlled air to one compartment to the exclusion of the other.

FIG. 2 is a schematic diagram of another embodiment of the HVAC system 10 according to another embodiment of the present invention. The HVAC system 10 of this embodiment includes a primary coolant loop 170 that includes a first refrigerant and a secondary coolant loop 172 that includes a second refrigerant. The first refrigerant in the primary coolant loop 170 is driven by the compressor 14 which passes through

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the condenser 16, the receiver and dryer 18, the refrigerant metering device 20, the first refrigerant-to-second refrigerant heat exchanger 174, and back to the compressor 14.

In contrast, the second refrigerant in the secondary coolant loop 172 is driven by a low pressure liquid pump 176. The fluid passes through a second refrigerant-to-air heat exchanger 178, a heater 180, and the first refrigerant-to-second refrigerant heat exchanger 174. The first refrigerant-to-second refrigerant heat exchanger 174 serves as the heat exchange medium between the primary coolant loop 170 and the secondary coolant loop 172. The second refrigerant-to-air heat exchanger 178 cools the air supplied by the circulation blower 210, which then flows to the vehicle compartment with or without ducting. To provide heating of the vehicle compartment, the power management controller 50 need only operate the low pressure liquid pump 176 and the heater 180 in the secondary coolant loop 172 and the circulation blower 210. That is, no power is delivered to the compressor 14, and as a result the amount of power consumption is further reduced, which extends the time duration that heating may take place.

FIG. 3 shows an alternative configuration of FIG. 2 in which there are two second refrigerant-to-air heat exchangers 178 and 182 in the secondary coolant loop 172. One second refrigerant-to-air heat exchanger 178 may be used to provide cooling/heating to the driving compartment 23 while the other heat exchanger 180 may be used to provide cooling/heating to the sleeping compartment 27 with or without ducting. The passage of the liquid through either or both of the heat exchangers 178 and 182 can be selected by the power management controller 50, which, in turn, controls the valve 184 that leads to the heat exchanger 180 and the valve 186 that leads to the heat exchanger 178. Thus, the control of the valves 184 and 186 permits the driving compartment 23, the sleeping compartment 25, or both compartments to be air conditioned or heated at a particular time.

FIG. 4 shows another embodiment of the present invention in which the HVAC system uses a reverse cycle heating system. The reverse cycle heating system also allows the heating function to be completed without relying on the engine or additional fuel by merely relying on the compressor and the circulation blowers, which are powered by the first and/or second power sources or the vehicle electrical power generation system. As with the embodiment shown in FIG. 1, the HVAC system 10 of FIG. 4 may comprise a motor 12, a compressor 14, circulation blowers 210 and 212, power management controller 50, and a battery management system 60. The motor may be a brushless DC or a synchronous permanent magnet motor, which is operatively coupled to the compressor 14. The compressor 14 is a continuously variable speed compressor, which is driven by the motor 12. Connected to the compressor is a reversing valve 502, which allows the compressor to pump refrigerant in a cooling direction indicated by single arrows 520 or a heating direction indicated by double arrows 522.

As to the cooling direction, the compressor 14 circulates refrigerant through a heat exchanger 504 (which functions as a condenser in the cooling mode as the hot compressed gas from the compressor condenses to a liquid as heat is given off) to a first flow path 510 that thermally treats air going to the driving compartment 23 and/or a second flow path 512 that thermally treats air going to the sleeping compartment 27 of the vehicle. As to the first flow path 510, the refrigerant passes through a refrigerant metering device 20 and a heat exchanger 506 (which functions as an evaporator in the cooling mode as the liquid refrigerant boils and forms a gas as heat is absorbed by the refrigerant liquid). Air is blown over the heat

exchanger **506** by the circulation blower **210**. After the air is cooled by the heat exchanger **506**, the air proceeds towards the driving compartment **23** of the vehicle.

A second flow path **512** runs parallel to the first flow path **510** in which the refrigerant is provided through a refrigerant metering device **24** and a heat exchanger **508** (which functions as an evaporator during the cooling mode as the liquid refrigerant boils and forms a gas as heat is absorbed by the refrigerant liquid). Air is blown over the heat exchanger **508** by a circulation blower **212**. After the air is cooled by the heat exchanger **508**, the air proceeds towards the sleeping compartment **27** of the vehicle. The heat exchanger **508** of the second flow path **512** may be smaller than the heat exchanger **506** of the first flow path **510** because the sleeping compartment **27** is typically smaller than the driving compartment **23**.

The two coolant loops may be selectable through the use of valves **28**, **29**, **514**, and **516**. The inclusion of such valves permits the driving compartment **23**, the sleeping compartment **25**, or both compartments to be air conditioned at a particular time. The valves **28** and **514** are opened and the valves **29** and **516** are closed when only the driving compartment is being temperature controlled. By a similar token the valves **29** and **516** are opened and the valves **28** and **514** are closed when only the sleeping compartment is being temperature controlled. The valves **28**, **29**, **514**, and **516** may be controlled through the power management controller **50**. Once the refrigerant passes through the heat exchanger **506** and/or **508**, the refrigerant then returns to the reversing valve **502** and the compressor **14** to restart the process.

As to the heating direction, the reversing valve **502** is switched such that the refrigerant pumped by the compressor flows in the reverse direction as indicated by double arrows **522**. Thus, the compressor causes the refrigerant to flow through the first flow path **510** and/or the second flow path **512** depending if the valves **28** and **514** and the valves **29** and **516** are opened or closed. If the valves **28** and **514** are opened, the refrigerant flows through the heat exchanger **506** (which functions as a condenser in the heating mode as the hot gas is condensed to a liquid as it gives up heat). Air is blown over the heat exchanger **506** by the circulation blower **210**. After the air is heated by the heat exchanger **506**, the air proceeds towards the driving compartment **23** of the vehicle. Meanwhile, the refrigerant continues from the heat exchanger **506** through the refrigerant metering device **20** to the heat exchanger **504** (which functions as an evaporator in the heating mode). After flowing through the heat exchanger **504**, the refrigerant returns to the reversing valve **502** and the compressor **14**.

If the valves **29** and **516** are opened, the refrigerant flows through the heat exchanger **508** (which functions as a condenser in the heating mode). Air is blown over the heat exchanger **508** by a circulation blower **212**. After the air is heated by the heat exchanger **508**, the air proceeds towards the sleeping compartment **27** of the vehicle. Meanwhile, the refrigerant continues from the heat exchanger **506** through the refrigerant metering device **24** to the heat exchanger **504** (which functions as an evaporator in the heating mode). After flowing through the heat exchanger **504**, the refrigerant returns to the reversing valve **502** and the compressor **14** to restart the process.

Similar to the embodiment shown in FIG. 1, the embodiment of FIG. 4 may include a variable speed compressor **14** driven by a brushless DC or a synchronous permanent magnet motor **12**; the control for the heating and cooling operations being provided by the power management controller **50**. The available power sources may include a first power source **40**, a second power source **42**, and/or the vehicle's main electrical

power generation system **44**. If a power system **70** is utilized, the available power sources may come from the power system **70** as seen in FIG. 10 and discussed further below. The circulation blowers **210** and **212** may also have continuously variable speed which may be controlled by the power management controller **50**; and the battery management controller **60** can monitor and control the available power sources when the engine is turned off.

Also as with the embodiment of FIG. 1, FIG. 4 may include alternative configurations. For example, the first or the second cooling path may be eliminated such that there is only one refrigerant metering device, one heat exchanger in which air passes over, and one blower. With this configuration only one vehicle compartment may be temperature controlled. Alternatively, ducting may be used in which the duct channeling the temperature controlled air may be spit into multiple channels such that a first channel goes to the driving compartment and a second channel goes to the sleeping compartment. In this embodiment, a control door or the like may be used to channel the temperature controlled air to one compartment to the exclusion of the other.

The power requirements and operation of the HVAC system **10** are handled by the battery management controller **60** and the power management controller **50**, respectively. The two controllers **50** and **60** may be software control loops with associated hardware or circuitry, and they may be physically housed in separate devices or the same device.

The battery management controller **60** will now be discussed with reference to FIG. 5(a). The battery management controller **60** can fulfill a variety of different purposes including: (1) maximizing the electrical power available for use by the HVAC system; (2) ensuring that sufficient electrical reserve power is available to start the engine; (3) tracking historical use (charge and discharge) of all connected batteries; (4) determining the current state of charge of all connected batteries; (5) determining the current end-of life status of all connected batteries irrespective of their respective charge level; (6) ensuring that the charge and discharge cycles of all connected batteries are consistent with the user's preferred compromise between battery longevity and available stored energy; and (7) prevent overloading of the battery charging system.

The battery management controller **60** carries out its function by being connected to a plurality of power sources **40** and **42**, a combination/separation device **61**, and a charging device **61**. In one exemplary embodiment, a truck can have seven batteries in which four batteries are connected in parallel to provide a high capacity first battery bank as the first power source **40** and the three remaining batteries are connected in parallel to provide a second, somewhat smaller battery bank as the second power source **42**.

The first power source **40** and/or the second power source **42** are connected to a separation device **61**, temperature and voltage sensors **63**, and an engine starter **64**. The first and second power sources (e.g., the first and second battery banks) are connected to the combination/separation device **61** so as to allow the first and second power sources to be electrically combined or separated.

The combination/separation device **61** can be electrically connected to supply power to the individual components of the HVAC system **10** and can optionally be connected to other electrical power accessories, such as microwave ovens, televisions, stereos, refrigerators, etc. The combination/separation device **61** is configured to electrically split and combine multiple power sources so as to maximize the availability of power to the components of the HVAC system **10** and the engine starter **64**. Furthermore, the combination/separation

device 61 can electrically split and combine multiple batteries to prevent overloading of a charging device 62, such as an alternator, by selectively combining the discharged power sources into a partially charged pack.

The temperature and voltage sensors 63 can monitor the voltage and temperatures of the first and second power sources 40 and 42. These sensors can be used to monitor the state of charge of the power sources so as to prevent the power sources from being overly discharged.

The engine starter is connected to one of the power sources so as to provide enough power to start the engine of the vehicle. The engine starter 64 can be electrically connected to the first power source or the second power sources but not to both. Also, the engine starter 64 may have an optional connection 65 that leads directly to the combination/separation device 61.

The charging device 62 can be connected to the combination/separation device 61 so that the electrical power output from the charging device 62 can be selectively routed to any individual or combination of connected power sources. The charging device can comprise one or more of the following: the engine alternator, an accessory generator, a show power connection, and other charging devices.

The battery management controller 60 can include a control logic circuit 66 and a memory 67, and can be connected to the voltage and temperature sensors 63, a user interface 51 (which can comprise a display 310 and one or more input devices 312), the combination/separation device 61, and the power management controller 50. Thus, the battery management controller 60 can receive measurements from the voltage and temperature sensors 63 and user preferences from the user interface 51. Additionally the battery management controller 60 can receive and transmit information in a bi-direction manner to and from the power management controller 50. The battery management controller 60 is used to regulate the degree of discharge among the power sources so as to conform to the user preferred compromise between the daily battery performance and the ultimate life of the power sources. In addition, the memory 67 of the battery management controller can be used to log historical data obtained during previous charge and discharge cycles, such as voltage and temperature levels, and use the historical data to modify the permitted depth of discharge to ensure the completeness of future charge cycles.

Additionally, the memory 67 may be connected to an input/output device 68 which allows the memory 67 to transmit data collected by the battery management controller 60 to the input-output device 68. The input/output device 68 can be any memory storage medium, including flash drives, such as USB memory sticks or CompactFlash cards, or hard drives. The battery management controller 60 may be configured so that a vehicle user uses the interface 51 to sample system data, such as voltage and temperature levels, or any other data which may be sampled by the battery management controller 60. The input/output device 68 is useful when a user instructs the battery management controller 60 through the interface 51 to sample the system data at a preferred sampling rate (e.g., every 10 seconds). The data is stored in the memory 67, and transmitted to the input/output device 68. The input/output device 68 is preferably a very large memory bank so several months worth of data can be recorded.

In a more conventional HVAC system, the measurement of the battery voltage under load is used to determine the state-of-charge. While this method is low in cost and easy to implement, it is also highly inaccurate. The voltage can be used to accurately determine the state-of-charge but only when such measurements are taken in conjunction with temperature and

only after the battery has been "at rest" (i.e., unloaded) for a period or time (typically over one hour). In contrast, the battery management controller 60 of FIG. 5(a) can use multiple sources of historical and real-time data to more accurately determine the amount of stored energy available for use. Additionally, the battery management controller 60 allows a highly accurate "resting voltage" measurement of the state of charge to be made of the power reserve even when portions of the battery power supply are still in use. Below is a discussion of the processes that occur during the discharging of the power sources when in the engine is turned off, the starting up of the engine, and the charging of the power sources when the engine is turned on. In the discussion below, the first and second power sources are battery banks but is should be recognized that any type of power source can be used. For example, one of the first and second power sources may be an external AC connection.

The process that the battery management control circuit undergoes during discharge is provided in FIG. 6(a). The discharging of the first and/or second battery banks occurs when the engine is turned off as shown in step 402, and a command is issued from the power management controller 50 ("PMC") to the battery management controller 60 ("BMC") to supply power to the components of the HVAC system 10 as shown in step 404. In step 406, upon receiving the command from the power management controller 50, the battery management controller 60 through its control circuit 66 would determine the state of charge of the combination of the first and second battery banks by comparing the current voltage and temperature of the combined banks from data received by the voltage and temperature sensors 63 with the historical data stored in the memory 67 of the controller 60. If there is sufficient charge with both power sources, the process proceeds to step 408. If there is not sufficient charge, the process proceeds to step 430.

At step 408, upon determining that sufficient stored energy was available for use, the first and second battery banks 40 and 42 would be electrically combined through the combination/separation device 61 so as to supply power to the components of the HVAC system 10. The power draw (current) from the HVAC system 10 is monitored and the rate of decline in the combined battery banks 40 and 42 is noted. The power draw and rate of decline is compared to historical data to determine the approximate state of sulfation of the battery plates and from this comparison, the approximate condition of the batteries is deduced. Under a given load, the voltage of batteries in poor condition will decline faster than batteries in good condition. Consequently, it can be predicted that batteries in poor condition will have less total stored energy even though the actual voltage at any given time may be the same. In one example, data can be collected related to the maximum battery discharge and/or the average battery discharge during an operation cycle of the power sources when the power sources are batteries. This data can be compiled over time such that a history of the maximum and/or average battery discharge is stored in the memory 67 in the battery management controller 60.

As the voltage of the combined batteries falls, the battery management controller logic circuit 66 will use the temperature, the load, the rate of voltage change, the estimated battery condition, the stored historical data and the user preference inputted from the user interface 51 to determine the preferred voltage point at which to separate the first and second battery bank 40 and 42 using the combination/separation device 61. The user interface can comprise a display 310 and one or more input devices 312, such as a keyboard, a control panel, or the like, so that the vehicle occupant can input user pref-

ferences for the operation of the HVAC system **10**. For example, the user preferences can include the operating mode of the HVAC system such as off, heating, and cooling modes of operation. Additionally, the interface **51** can include a programmable timing device **314** so that the operating mode of the HVAC system **10** is determined based on time values instead of user inputs. For example, the timing device **314** may be programmed so that the heating is turned off at a certain time (e.g., 6:00 a.m.) or after a certain amount of time (e.g., 6 hours).

The user preferences which are inputted using the user interface **51** are also those factors that influence the extent to which the battery banks **40** and **42** will be allowed to be discharged. One example is the battery replacement life. Battery replacement life is related to the depth of the discharge of the power source as well as the rate of discharge, i.e., a function of the minimum battery voltage adjusted by the load. For example, a lightly loaded battery which is consistently discharged to 11.8 V may only last through 100 charge/recharge cycles while a heavily loaded battery that was consistently discharged to 11.8 V might last 200 charge/recharge cycles. If a user preference is set for a long battery life, the batteries will be less deeply discharged and will last longer. However, because less stored energy will be available for use, more batteries will need to be carried to supply a given amount of cooling or heating than would be the case if a shorter battery life (and more deeply discharged batteries) were selected.

In addition, the display **310** of the user interface **51** can provide a user, such as a vehicle occupant, information related to the status of the HVAC system **10**. The display can include one or more of an alphanumeric display, a graph, or the like. For example, the display can include the vehicle's interior ambient temperature, the exterior ambient temperature, the circulation blower speeds, the usage of the power source or sources supplied to the HVAC system **10**, and warning messages, etc. In one example, if the first power source and the second power source are batteries, the display can show the current approximate battery charges for each power source to the vehicle occupant.

As the HVAC operation continues, the combined battery bank voltage can be continually monitored. The preferred voltage point is determined based on the temperature, the load, the rate of voltage change, the estimated battery condition, the stored historical data and user preferences such that the preferred voltage point becomes a predetermined amount of voltage that is dynamically determined based on ambient operating conditions in which the first and second power sources separate if the combined voltage drops below the predetermined amount. If the voltage does not drop below the preferred voltage point, the monitoring of the power draw and rate of decline is continued. If the combined bank voltage eventually falls to the preferred voltage point, the battery management controller logic circuit **66** commands the combination/separation device **61** to electrically separate the first and second battery banks **40** and **42** at step **410**. Once separated, the HVAC power is supplied solely by the first battery bank **40** while the second bank (i.e., the battery bank connected to the engine starter **64**) is isolated and the voltage of the second battery bank partially recovers to an unloaded resting state. In time it will be possible to use this "resting" voltage to accurately determine the state of charge of the isolated bank. Then, a determination will then be made by the control logic circuit **66** about whether additional power can be safely drawn from the isolated bank.

With continued operation of the HVAC system **10**, the voltage of first battery bank **40** continues to decline. The

battery management controller logic circuit re-analyzes the battery bank **40** by comparing real time data on the power draw, the temperature and the rate of voltage decline with the stored historical data and the user input preferences to determine the amount of stored energy available. A determination is made of the minimum system disconnect voltage, i.e., the battery cut-out voltage. From this determination, a calculation is made of the estimated time to battery depletion for the first battery and this estimated time information is communicated to the power management controller **50**. Because the estimated time information is based on both static data (such as historical and user input) and real-time data (such as current voltage levels and temperatures), a change in the performance, the system load or the ambient conditions during the operation of the HVAC system **10** can change the estimated time information which may increase or decrease the calculation of the available system run time.

As the HVAC system **10** continues to run, the voltage level of the first battery is monitored in step **410**. As long as there is sufficient voltage, the battery management controller will continue to have the first battery bank power the HVAC components and monitor the first battery bank's voltage level. However, the power can eventually be depleted from the first battery bank **40** to the point where the voltage falls to the level calculated by the control logic circuit to be the minimum allowed, i.e., the battery cut-out voltage, and disconnect the first battery bank **40** as shown in step **412**. If continued operation of the HVAC system **10** is desired, the battery management controller logic circuit **66** will use the resting voltage measurement of the second battery bank **42** (which has been isolated) to determine how much, if any, additional power can safely be drawn from that bank at step **414**. If power is available from the second battery bank (the "YES" path), the control logic circuit **66** will set a second lower voltage level at step **416** and command the combination/separation device **61** to re-route power from the second battery bank **42**. As the HVAC system **10** continues to run, the voltage level of the second battery is monitored. If the voltage level remains above the second voltage, the process remains at step **416**. Power will then continue to be supplied by the second bank **42** until such time as the voltage of the second bank **42** falls below the second lower voltage. At that time, the battery management controller logic circuit will command the combination/separation device **61** to cut off all power to the HVAC system **10** at step **420**. However, if no additional power is available from the second bank **42**, the battery management controller logic circuit will just command the combination/separation device **61** to cut off all power to the HVAC system **10** at step **420**.

In contrast, if there is insufficient charge in both battery banks at step **406**, the battery management controller determines if there is sufficient charge in one of the battery banks at step **430**. If there is not sufficient charge in either battery bank (the "NO" path), the battery management controller logic circuit will command the combination/separation device **61** to cut off all power to the HVAC system **10** at step **430**. If there is sufficient charge in one of the battery banks (the "YES" path), the particular battery bank with sufficient charge would supply power to the components of the HVAC system **10** at step **432**. The battery management controller logic circuit analyzes the selected battery bank by comparing real time data on the power draw, the temperature and the rate of voltage decline with the stored historical data and the user input preferences to determine the amount of stored energy available. A determination is made of the minimum system disconnect voltage, i.e., the battery cut-out voltage. From this determination, a calculation is made of the estimated time to

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battery depletion for the selected battery and this estimated time information is communicated to the power management controller 50. Because the estimated time information is based on both static data (such as historical and user input) and real-time data (such as current voltage levels and temperatures), a change in the performance, the system load or the ambient conditions during operation of the HVAC system 10 can change the estimated time information which may increase or decrease the calculation of the available system run time.

As the HVAC system 10 continues to run, the voltage level of the selected battery bank is monitored. If there is sufficient voltage, the battery management controller will continue the monitoring process. However, the power can eventually be depleted from the selected battery bank to the point where the voltage falls to the level calculated by the control logic circuit to be the minimum allowed, i.e., the battery cut-out voltage. Once the voltage level falls below this minimum, the battery management controller logic circuit will command the combination/separation device 61 to disconnect the selected battery bank at step 434; thus cutting off all power to the HVAC system 10 at step 420.

At the end of the discharge cycle, the battery management controller 60 has regulated the battery banks 40 and 42 so that the first battery bank 40 is more deeply discharged than the second bank 42. Additional power has been reserved in the second battery bank 42, which is the bank to which the engine starter 64 is connected, thus ensuring that sufficient energy is available to start the engine. Because the charge level of the two banks is different, the voltage level is also different. Therefore, the battery management controller logic circuit 66 commands the combination/separation device 61 to keep the two battery banks electrically separated and can monitor the voltage of each bank individually.

At the start up of the engine, a heavy electrical load is applied to the second bank 42 causing the voltage of the second bank 42 to drop. The amount of drop depends on the condition, the state of charge, and the temperature of the second bank 42 as well as the engine itself. Thus, there is a chance that under certain adverse conditions, the voltage drop will be so severe as to prevent the engine from starting unless additional electrical power is made available.

By monitoring the voltage of the first bank 40 separately from the second bank 42, and by monitoring the rate of charge of the voltage in the second bank 42 at the time the electrical load is applied at the engine start up cycle, the battery management controller logic circuit 66 can determine if additional electrical power is available in the first battery bank 40 to provide a starting boost. If the control algorithm in the battery management controller logic circuit 66 determines that such power is available, the logic circuit 66 will command the combination/separation device 61 to electrically combine the first battery bank 40 with the second battery bank 42 during the engine start up cycle. In this case, the engine starter 64 is connected to the combination of the first and second battery banks 40 and 42 through the combination/separation device 61 via the optional connection 65; thus allowing the engine to be started. After the engine is started, the battery management controller logic circuit switches to its charge mode algorithm as will be described next.

FIG. 6(b) is a flow chart showing the process for charging the batteries after the engine has been turned on. After the engine has started up at step 450, one or more power sources can be used to recharge the first and second battery banks 40 and 42. When the charging device 62 (such as the alternator) is activated at step 452, the battery management controller logic circuit 66 reviews the historical data from the last dis-

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charge cycle to estimate the amount of load that the recharging operation will be put on the charging device 62 at step 454. Previously entered user input from the user interface 51 will be used to determine if this estimated load is "high" or "low."

A deeply discharged battery bank and/or large battery banks that contain a great deal of storage capacity are more likely to cause a "high" load than smaller or more lightly discharged batteries. Therefore, if the estimated load is determined to be "high," the battery management controller logic circuit commands the combination/separation device at step 456 to route the electrical power from the charging device 62 to only to the second battery bank 42 (i.e., the bank connected to the engine starter 64). Once the second bank has reach a state of charge sufficient to significantly reduce the load on the charging device 62, the control logic circuit commands the combination/separation device 61 at step 458 to electrically combine the first and second battery banks 40 and 42 so that all batteries get recharged. If, at the beginning of the recharge cycle, the battery management controller logic circuit determines that the load will be "low" then all batteries from both the first and second battery banks 40 and 41 are combined via the combination/separation device 61 and charged together at step 460. From either step 458 or step 460, the charging of both battery banks is continued until both are fully charged or the engine is turned off at step 462.

According to one embodiment of the present invention, so as to ensure that the batteries are fully recharged between cycles to prevent premature sulfation and destruction of the batteries, the battery management controller can also monitor and store the time and power levels of the batteries during the discharge and recharge cycles. This historical data can verify that, in a typical discharge and re-charge cycle, sufficient time and power is available to fully recharge the batteries. If there is not sufficient time and power to fully recharge, the control logic circuit 66 can respond by raising the minimum battery cut-off voltages thereby reducing the total amount of power which can be drawn from the battery banks. In other words, the battery management controller 60 can be configured to be self-learning which allows the controller to maximize the battery replacement life by monitoring the first and/or second power sources such that they are not excessively discharged (i.e., drained) and such that they are not discharged to a level that does not allow the power source to be fully recharged during the typical engine run time. For example, consider that a power source might be a battery in which the battery can be safely discharged to a level X. Thus, the level X can be the predetermined amount value during the determination of whether the power source should be connected to the HVAC system. However, if the run cycle of the engine was too short to allow the battery to fully recharge during the engine run after the battery had been partially discharged, the battery would still be prematurely destroyed because failure to fully recharge a battery is just as harmful as discharging it too deeply (or draining the charge too much). To prevent the premature destruction of a battery due to it not being fully recharged, the battery management controller 60 can monitor the battery charge in the power source to determine if the battery was fully recharged. If the battery was not, then the controller 50 can be configured to "learn" during the next operation where the power source is connected and the engine is turned off that the battery should be less deeply discharged, i.e., the battery should be discharged to a level Y, which is greater than the level X. Then, the level Y can be the predetermined amount value during the determination of whether the power source should be connected to the HVAC system.

Next, the power management controller 50 will be described. The power management controller 50 controls the



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components of the HVAC system 10, and works in conjunction with the battery management controller 60. The purpose of the power management controller 50 is to: (1) communicate to the user via the user interface; (2) monitor safety functions and initiate appropriate responses; (3) maximize the operational efficiency of the HVAC system by optimizing the speed of the condenser and evaporator fans and the speed of the compressor motor according to ambient conditions and user preferences; (4) regulate the speed of the condenser fans to control the condenser temperature thereby obtaining the best compromise between increased fan motor power consumption and increased compressor motor power; (5) regulate the speed of the evaporator fan proportionate to the temperature differential between the user temperature set point and the actual ambient temperature; and (6) regulate the speed of the compressor motor to maintain the desired evaporator temperature.

The power management controller 50 carries out its function by being operationally connected to the battery management controller 60, the user interface 51 (which includes a display 310 and one or more inputs 312), a plurality of sensors, and the operational components of the HVAC system as shown in FIG. 5(b). The plurality of sensors detects a variety of parameters including: the vehicle's interior ambient temperature detected by a temperature sensor 304, the humidity of the vehicle's compartments by using a humidity sensor 307, and noise and/or vibration from one or more noise or vibration sensors 308.

As to the operational components of the HVAC system, the power management controller 50 can run the motor 12 that drives the compressor 14; the circulation blowers that blow the temperature-controlled air into one or more designated compartments (such as the vehicle compartment 23 and/or the sleeping compartment 27); the heaters for the heating system (such as the air heaters 272 and 274 from FIG. 1 or the heater 180 from FIG. 2); and the control doors (if applicable) for the regulation of the temperature. Additionally the power management controller 50 can also switch any control valves to control the flow of refrigerants (such as the valves 28 and 29 from FIG. 1 or the valves 184 and 184 from FIG. 2). In one embodiment, the motor 12 of the compressor 14 can be controlled by the power management controller 50 using a closed loop proportional, integral, derivative (PID) control. Similarly, the power management controller 50 can also control the fan speed of the circulation blowers 210 and 212 via a pulse width modulated (PWM) PID control loop that is independent of the control for the compressor.

In one embodiment, the power management controller 50 can modulate the speed of the motor 12, and thus can modulate the capacity of the compressor 14 driven by the motor 12. The modulation of the compressor can range between an upper compressor capacity and a lower compressor capacity. The compressor capacity can vary depending on the compressor capacity required to maintain the evaporator 22 or 26 at the evaporator temperature  $T_E$  as commanded by the power management logic circuit 66.

In one exemplary embodiment of the present invention, the power management controller 50 ("PMC") can work as described below with reference to FIG. 7. The power management controller 50 receives a signal from the user interface 51 to begin operation at step 702. Commands are sent to the battery management controller 60 ("BMC") from the power supply management controller 50 to supply power to the HVAC system 10 at step 704. The user interface 51 is polled for the user preference settings, such as the mode of operation, the location of temperature control, and the desired

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set point temperature  $T_{sp}$ . Also the ambient temperature  $T_a$  is read from the temperature sensor 304 at step 706.

If the user preference is for the "cooling" mode, the process is sent to step 708 where a command is issued to start all fans of the circulation blowers 210, 212 and the motor 12 of the compressor 14 to a minimum speed. At step 710, the compressor speed is then commanded to bring and hold the evaporator 22 to a predetermined evaporator temperature  $T_E$  if the vehicle compartment is being cooled or to bring and hold the evaporator 26 to a predetermined evaporator temperature  $T_E$  if the sleeping compartment is being cooled. At step 712, the fans of the condenser 16 are commanded to bring and hold the condenser 16 to a predetermined condenser temperature  $T_C$ .

If the user preference is for the "heating" mode, a command from the power management controller 50 is issued at step 714 to start the fans of the circulation blowers of the evaporator 22 or 26. The electric heating element 270 or 274 is commanded at step 716 to a power level (via PWM control) proportionate to the fan speed of the circulation blowers of the evaporator 22 or 26.

With the HVAC system 10 now running in either the heating or cooling mode, the battery management controller 60 is polled for an estimate of the run time based on the present power draw and stored energy available for use in step 718. As step 720, the estimated run time is compared to the desired run time which was programmed into the user settings by the user using the user interface 51. The power management controller factors the difference between the estimated and desired run times into planning the output of the HVAC system 10 to ensure that sufficient power is available for the duration of the heating or cooling period (also called the "run time plan"). Based on the run time plan, the power management controller 50 may increase or decrease the average capacity of the HVAC system periodically throughout the cycle. In particular, if the amount of heating (steps 726 and 736) or the amount of cooling (steps 726, 728, and 730) would require too much power to be drawn from the power source(s), the highest capacity of the HVAC system 10 possible would be employed which would still allow the battery management controller to supply power through the entire operational period. The highest capacity possible can be obtained through a combination of settings which would offer the best efficiency for the prevailing conditions.

At step 722, a variety of measurements are taken at step 722 so as to ensure that the HVAC system runs efficiently with its limited power supply. These measurements include the actual ambient temperature of the vehicle's interior  $T_a$ , the evaporator temperature  $T_E$ , and the condenser temperature  $T_C$ . At step 722, temperature sensors on the evaporator measure the evaporator temperature  $T_E$ , temperature sensors on the condenser measure the condenser temperature  $T_C$ , sensors in the vehicle and/or sleeping compartments measure the ambient temperature  $T_a$ , and the user inputs the desired ambient temperature or the set point temperature  $T_{sp}$  via the user interface 51.

For efficient operation of the HVAC components in either the cooling or heating mode, a calculation is made at step 724 in which a difference  $\Delta$  between the ambient temperature  $T_a$  and the set point temperature  $T_{sp}$  is determined. Then, the circulation blowers at the evaporator 22 or 26 are commanded to a speed proportionate to the difference  $\Delta$  at step 726. The determination of an appropriate fan speed for the blowers at the evaporator based on a given  $\Delta$  can be based on any one of a number of methods known in the art such as tabular formulations or computer models.

The air blown into the vehicle and/or sleeping compartments affects the ambient temperature of the compartment;



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thus with continued operation of the HVAC system, the difference ( $\Delta$ ) between the ambient temperature  $T_a$  and the set point temperature  $T_{sp}$  begins to decrease. As the ambient temperature  $T_a$  nears the set point temperature  $T_{sp}$ , the power management controller 50 reduces the fan speed of the circulation blowers at the evaporator 22 or 26 proportionately based on  $\Delta$ , as seen in step 726. If the system is in the cooling mode, the reduced air flow over the evaporator 22 or 26 causes the evaporator temperature  $T_E$  to fall. In response, the power management controller 50 adjusts the speed of the motor 12 that drives the compressor 14 to maintain the desired evaporator temperature  $T_E$  at step 728. Similarly, the changing capacity of the evaporator 22 or 26 also changes the temperature of the condenser  $T_C$ . Again, the power management controller 50 adjusts the fan speed of the condenser 16 so as to maintain the desired condensing temperature  $T_C$  at step 730. However, the settings for the circulation blowers, the compressor, and the condenser (which are set in steps 726, 728, and 730 respectively) are subject to the highest possible capacity of the HVAC system based on the run time plan. Thus, if too much power would be drawn by these components while running at the most efficient operation, the settings of these components would be adjusted so as to allow the system to run for the desired run time while operating as close as possible to the most efficient operation determined by  $\Delta$ .

The process continues to step 732 where the power management controller receives data from the battery management controller 60 about whether there is sufficient power being supplied. If there is sufficient power (the "YES" path), the process returns to step 718 and the process is repeated. If there is insufficient power (the "NO" path), the operation of the HVAC system is terminated at step 734.

If the HVAC system is operating in heating mode rather than the cooling mode, the power management controller 50 alters the PWM cycle of the resistive heating elements 270 or 274 to match the changing fan speed of the circulation blower at the evaporator 22 or 26. In this way, the temperature of the discharged air remains constant. Thus, step 736 is carried out in FIG. 7 instead of steps 728 and 730. Similar with the cooling operation, the settings for the circulation blowers and the heater (which are set in steps 726 and 736 respectively) are subject to the highest possible capacity of the HVAC system based on the run time plan. Thus, if too much power is being drawn by these components while running at the most efficient operation, the settings of these components can be adjusted so as to allow the system to run for the desired run time while operating as close as possible to the most efficient operation determined by  $\Delta$ . For example, the settings of the circulation blowers may be lowered to a level that permits operation during the entire desired run time while still operating as close as possible to the settings for the most efficient operation based on  $\Delta$ .

Other system parameters can be used to control the motor-driven compressor 14 and the circulation blowers 210 and 212. For example, the power management controller 50 can also monitor humidity of the vehicle's compartments by using a humidity sensor 307. If the humidity of the compartments is above a predetermined threshold (which can be set by the vehicle occupant), the power management controller 50 can control the compressor 14 to speed up (up to but not exceeding the upper compressor capacity) and the circulation blowers 210 and 212 to slow down.

Furthermore, one or more noise or vibration sensors 308 can be used to determine the level of noise or vibration of the HVAC system 10. Once the signal is sent to the power management controller 50, the controller 50 determines whether

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there is a need to speed up or slow down the compressor and/or blower, and to control the compressor and/or blower accordingly.

The use of one or more system parameters, such as the evaporator temperature, the humidity, the exterior ambient temperature, the vehicle's interior temperature, etc. to control the compressor and blower capacities can be accomplished by monitoring the one or more system parameters and using a program in the power management controller 50 that was compiled using, for example, a multivariate model known in the art.

Other system parameters can also be provided to the power management controller 50, which may allow the power management controller 50 to detect faults within the HVAC system. For example, performance and safety functions are monitored and an appropriate response by the power management controller 50 can be initiated, such as shutting down the system in the event of the overheating of the motor 12 of the compressor 14.

Additionally, sensor measurements utilized by the power management controller 50 may be stored in the memory 67 of the battery management controller 60. For example, the vehicle's interior ambient temperature detected by the temperature sensor 304, the humidity of the vehicle's compartments detected by humidity sensor 307, and noise and/or vibration levels detected by noise or vibration sensors 308 may all be transferred by the power management controller 50 to the memory 67 of the battery management controller 60. Additional measurements which can be stored in memory 67 include the actual ambient temperature of the vehicle's interior  $T_a$ , the evaporator temperature  $T_E$ , and the condenser temperature  $T_C$ , the evaporator measure the evaporator temperature  $T_E$ , condenser temperature  $T_C$ , ambient temperature  $T_a$ , and set point temperature  $T_{sp}$ .

The input/output device 68 containing the system's historical data collected by the battery management controller 50 may then be sent to a relevant party, such as the system manufacturer, for analysis of the system's performance. The data may be used to determine the real conditions from the field, to diagnose malfunctioning systems, and/or for engineering testing, etc. The data may also be used by trucking fleets for managing the system's use. For example, the data can provide a fleet manager information such as how long a truck was running, how long the air conditioner was running, etc.

FIG. 8 shows another embodiment of the HVAC system according to the present invention. The embodiment in FIG. 8 is similar to the embodiment of FIG. 1; however, FIG. 8 shows how the HVAC system can be divided up into a split system 600 in which there is an exterior subsystem 602 and an interior subsystem 604. The exterior subsystem 602 can comprise components that are located on the exterior of the vehicle's cab. The interior subsystem 604 can comprise components that are located in the interior of the vehicle's cab. For example, FIG. 8 shows an exterior subsystem 602 that comprises a motor 12, a compressor 14, a condenser 16, and a first power source, which are located outside the cab of a large vehicle, such as a truck. In addition, the second power source and the electrical power generation system 44 can also be located on the exterior of the vehicle's cab as is conventional with large vehicles.

The interior subsystem 604 can comprise the circulation blower 610, the evaporator 622 and the power management controller 50, the battery management controller 60, the display 310, and the input device 312, which are all located inside the cab of the vehicle. The temperature controlled air can be optionally channeled into ducts 672, which may split

into two or more ducts that may lead to different compartments or areas of the interior of the vehicle's cab. In one embodiment, the ducts 672 can be the vehicle's own ducting which is already installed in the vehicle cab. Additionally, the interior subsystem 604 can comprise the vehicle's already existing evaporator 622 and circulation blower 610. In such a situation, the exterior subsystem 602 may be configured to be able to connect to a plurality of different evaporators, such as the vehicle's own evaporator. In addition, the exterior subsystem 602 may be configured to connect to a plurality of evaporators at one time, such as one evaporator for cooling/heating the driving compartment and one evaporator for cooling/heating the sleeping compartment.

In FIG. 8, the refrigerant metering device is located exterior to the vehicle's cab as part of the exterior subsystem 602, which allows the servicing of the metering device to be easier if it should fail. Alternatively, the refrigerant metering device 20 can be located in the interior of the cab as part of the interior subsystem 604.

The split system 600 has several advantages. First, less interior space is taken up by the system because a substantial portion of the components are located exterior to the vehicle's cab. Additionally, the vehicle's existing ducts can be used so that no additional ducting is needed. Thus, the system can have an easier installation process, improved efficiency, and quieter operation.

FIG. 9(a) shows another embodiment of a split system in which an HVAC system 10 includes an installable HVAC system 10A, an installable module, that is to be installed in a vehicle with an existing HVAC system 10B. The components and their functions and operations in the embodiment of FIG. 9(a) are the same as disclosed in the discussion of the embodiment of FIG. 1 so the explanation of those components and functions are omitted. The embodiment of FIG. 9(a) further includes a housing H1. The installable HVAC system 10A may comprise the motor 12, the compressor 14, the power management controller 50, the battery management controller 60, the condenser 16, the optional refrigerant receiver and dryer 18, and the optional refrigerant accumulator 30 such that each of them are all installed within the housing H1. Thus, the installable HVAC system comprises those components coupled in a modular package for easy installation to an HVAC system already installed in the vehicle.

The existing HVAC system 10B comprises those components that have been already incorporated into the vehicle. In the embodiment of FIG. 9(a), the components of the existing HVAC system 10B include the circulation fans or blowers 210 and 212, the evaporators 22 and 26, the metering devices 20 and 24, the air ducts 272 and 276 leading to the driving and sleeping compartments 23 and 27 of the vehicle, the air heaters 270 and 274, and the valves 28 and 29. Also, the available power sources, such as the first power source 40, the second power source 42, and/or the vehicle's main electrical power generation system 44 are also located outside the housing H1. Fluid connections between the installable HVAC system 10A and the existing HVAC system may take the form of connection tubing or ducting from the housing of the installable HVAC system 10A to the individual components of the existing HVAC system 10B. Electrical connections from the power sources and/or individual components of the existing HVAC system to the installable HVAC system may take the form of wires, one or more detachable electrical cables, one or more detachable optical cables, or other transmission device.

FIG. 9(b) shows another embodiment of a split system in which an HVAC system 10 includes an installable HVAC system 10A, an installable module, that is to be installed in a vehicle with an existing HVAC system 10B. The components

and their functions and operations in the embodiment of FIG. 9(b) are the same as disclosed in the discussion of the embodiment of FIG. 1 so the explanation of those components and functions are omitted. The embodiment of FIG. 9(b) further includes a housing H2. The installable HVAC system 10A may comprise the motor 12, the compressor 14, the power management controller 50, the battery management controller 60, the condenser 16, the optional refrigerant receiver and dryer 18, the optional refrigerant accumulator 30, the circulation fans or blowers 210 and 212, the evaporators 22 and 26, the metering devices 20 and 24, the air heaters 270 and 274, and the valves 28 and 29 such that each of them are all installed within the housing H2. Also, the available power sources, such as the first power source 40, the second power source 42, and/or the vehicle's main electrical power generation system 44 are also located outside the housing H1.

The existing HVAC system comprises ducting already installed in the vehicle. The ducting may include those ducts that lead to the vehicle and sleeping compartments 23 and 27 of the vehicle. Fluid connections between the installable HVAC system 10A and the existing HVAC system 10B may take the form of connection tubing or ducting from the housing of the installable HVAC system to the individual ducts of the existing HVAC system. Electrical connections from the power sources and/or individual components of the existing HVAC system to the installable HVAC system may take the form of wires, one or more detachable electrical cables, one or more detachable optical cables, or other transmission device.

FIG. 9(c) shows another embodiment of a split system in which an HVAC system 10 includes an installable HVAC system 10A, an installable module, that is to be installed in a vehicle with an existing HVAC system 10B. The components and their functions and operations in the embodiment of FIG. 9(c) are the same as disclosed in the discussion of the embodiment of FIG. 2 so the explanation of those components and functions are omitted. The embodiment of FIG. 9(c) further includes a housing H3. The installable HVAC system 10A includes the primary coolant loop 170 with the motor 12, the compressor 14, the condenser 16, the receiver and dryer 18, the refrigerant metering device 20, and the first refrigerant-to-second refrigerant heat exchanger 174; the power management controller 50; and the battery management controller 60 in which each of these components are located within the housing H3.

The existing HVAC system 10B may comprise the secondary coolant loop 172 with the low pressure liquid pump 176, the second refrigerant-to-air heat exchanger 178, the heater 180, and the circulation blower 210. The modular form of the installable HVAC system 10A allows for easy connection to (possibly conventional) components and parts already present in existing vehicles. Fluid connections between the installable HVAC system 10A and the existing HVAC system 10B may take the form of connection tubing or ducting from the housing of the installable HVAC system 10A to the individual components of the existing HVAC system 10B. Electrical connections from the power sources and/or individual components of the existing HVAC system to the installable HVAC system may take the form of wires, one or more detachable electrical cables, one or more detachable optical cables, or other transmission device.

FIG. 9(d) shows another embodiment of a split system in which an HVAC system 10 includes an installable HVAC system 10A, an installable module, is to be installed in a vehicle with an existing HVAC system 10B. The components and their functions and operations in the embodiment of FIG. 9(d) are the same as disclosed in the discussion of the embodiment of FIG. 2 so the explanation of those components and

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functions are omitted. The embodiment of FIG. 9(d) further includes a housing H4. The installable HVAC system 10A includes the primary coolant loop 170 with the motor 12, the compressor 14, the condenser 16, the receiver and dryer 18, the refrigerant metering device 20, and the first refrigerant-to-second refrigerant heat exchanger 174; the power management controller 50; the battery management controller 60; and the secondary coolant loop 172 with the low pressure liquid pump 176, the second refrigerant-to-air heat exchanger 178, the heater 180, and the circulation blower 210 in which each of these components are located within the housing H4.

The existing HVAC system 10B comprises ducting already installed in the vehicle. The ducting may include those ducts that lead to the vehicle compartment 23. Fluid connections between the installable HVAC system 10A and the existing HVAC system 10B may take the form of connection tubing or ducting from the housing of the installable HVAC system 10A to the ducting of the existing HVAC system 10B. Electrical connections from the power sources and/or individual components of the existing HVAC system to the installable HVAC system may take the form of wires, one or more detachable electrical cables, one or more detachable optical cables, or other transmission device.

FIG. 9(e) shows another embodiment of a split system in which an HVAC system 10 includes an installable HVAC system 10A, an installable module, that is to be installed in a vehicle with an existing HVAC system 10B. The components and their functions and operations in the embodiment of FIG. 9(e) are the same as disclosed in the discussion of the embodiment of FIG. 3 so the explanation of those components and functions are omitted. The embodiment of FIG. 9(e) further includes a housing H5. The installable HVAC system 10A may comprise the primary coolant loop 170 with the motor 12, the compressor 14, the condenser 16, the receiver and dryer 18, the refrigerant metering device 20, the first refrigerant-to-second refrigerant heat exchanger 174; the power management controller 50; the battery management controller 60; and the secondary coolant loop 172 with the low pressure liquid pump 176, the valves 184 and 186; the second refrigerant-to-air heat exchangers 178 and 182, the heater 180, and the circulation blowers 210 and 212 in which each of these components are located within the housing H5.

The existing HVAC system 10B comprises ducting already installed in the vehicle. The ducting may include those ducts that lead to the vehicle and sleeping compartments 23 and 27. Fluid connections between the installable HVAC system 10A and the existing HVAC system 10B may take the form of connection tubing or ducting from the housing of the installable HVAC system 10A to the ducting of the existing HVAC system 10B. Electrical connections from the power sources and/or individual components of the existing HVAC system to the installable HVAC system may take the form of wires, one or more detachable electrical cables, one or more detachable optical cables, or other transmission device.

FIG. 9(f) shows another embodiment of a split system in which an HVAC system 10 includes an installable HVAC system 10A, an installable module, is to be installed in a vehicle with an existing HVAC system 10B. The components and their functions and operations in the embodiment of FIG. 9(f) are the same as disclosed in the discussion of the embodiment of FIG. 4 so the explanation of those components and functions are omitted. The embodiment of FIG. 9(f) further includes a housing H6. The installable HVAC system 10A may comprise the motor 12, the compressor 14, the circulation blowers 210 and 212, the power management system 50, the battery management system 60, the reversing valve 502, the heat exchanger 504, the refrigerant metering device 20,

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the heat exchanger 506, the refrigerant metering device 24, the heat exchanger 508, and the valves 28, 29, 514, and 516 in which each of these components are located within the housing H6.

The existing HVAC system 10B comprises ducting already installed in the vehicle. The ducting may include those ducts that lead to the vehicle and sleeping compartments 23 and 27. Fluid connections between the installable HVAC system 10A and the existing HVAC system 10B may take the form of connection tubing or ducting from the housing of the installable HVAC system 10A to the ducting of the existing HVAC system 10B.

The modular form of the installable HVAC system 10A in FIGS. 9(a)-9(f) allows for easy connection to (possibly conventional) components and parts already present in existing vehicles. The housings H1-H6 shown in FIGS. 9(a)-9(f) may be any suitable enclosure, such as a box of rectangular or other shape and made from sturdy materials, such as stainless steel, steel, plastic, or other suitable materials. The box may include one or more lids and/or access panels to permit access to the internal components housed within the housing. Electrical sockets or connectors may also be placed on the box for easy electrical connection. Installation of the installable HVAC system 10A to the vehicle may be implemented by attaching the housing H1-H6 at a suitable location on the vehicle, such as on the rear exterior surface of a truck's cab (as an exterior subsystem), on the floor in the interior of the sleeping or vehicle compartment (as an interior subsystem), or other suitable location. The housing H1-H6 may be attached by suitable fasteners to the vehicle, such as bolts, nails, straps, welding, or any combination thereof.

The housing H1-H6 of FIGS. 9(a)-9(f) permits the housing and its contents therein to be an exterior subsystem that is configured to connect to an evaporator, a plurality of evaporators, and/or ducting of the existing HVAC system of the vehicle. The battery management controller located in the housing of FIGS. 9(a)-(f) can be the battery management controller according to any embodiment disclosed herein. The power management controller located in the housing of FIGS. 9(a)-(f) can be the power management controller according to any embodiment disclosed herein. As a result, the housing H1-H6 of FIGS. 9(a)-9(f) includes sockets and connectors so as to electrically connect cables, wires, or other transmission devices to other electrical components external to the housing, for example, when the existing HVAC system includes a display 310, one or more input devices 312, and/or a combination/separation device 61 from FIGS. 5(a) and 5(b).

The compressor located within the housing may be a stepless variable speed compressor that is controlled by the power management controller and the HVAC system with the installable and existing HVAC systems has a cooling capacity of about 8000 BTU.

The disclosed battery management controller and HVAC system can provide temperature control to a vehicle occupant for extended periods of time when the vehicle's engine is not running. In addition, the system ensures sufficient battery power to start the vehicle even when the HVAC system has been running for a period of time when the engine has been turned off. The battery management and HVAC systems can be used in large trucks, such as tractor trailers or eighteen wheelers, as well as any other type of vehicle.

During operation, the power management controller 50 processes the user inputs to determine the operational mode of the HVAC system 10. When either the heating or cooling mode of operation is selected and when the engine is turned on, the vehicle electrical power generation system is used to power the necessary components. For example, the heater and

circulation blowers are turned on during the heating mode of operation while the compressor, circulation blowers, and pumps are turned on during the cooling mode of operation.

When the heating mode is operating when the engine is turned off, the power management controller **50** commands a heater (such as the coolant heater **180** in FIG. **2** or the air heaters **270** and **274** in FIG. **1**) and the circulation blowers **210** and **212** to turn on. The power management controller **50** also controls the speed of the circulation blowers **210** and **212** via a pulse width modulated (PWM) PID control loop in order to maintain the temperature of the driving and/or sleeping compartment at the interior set point temperature. With the various disclosed embodiments, the heating of the interior of the cab can be performed without relying on diesel fuel but can be run purely by battery power. Thus, the heating can be performed without relying on the vehicle's engine being turned on.

When the cooling mode of operation is used when the engine is turned off, the circulation blowers **210** and **212**, the compressor **14** and/or the pump **176** are turned on. The power management controller **50** modulates the capacity of the compressor **14** and the circulation blowers **210** and **212** to maintain the temperature of the driving and/or sleeping compartment at the interior set point temperature via PID control.

In either the heating or cooling mode when the engine is turned off, if the voltage of the combination of the first and second power sources drops below a predetermined amount, the first and/or second power source is disconnected and the HVAC system is only powered by the remaining power source. Once the voltage of the remaining power source drops below another predetermined level, the battery management controller **60** can be configured to disconnect the remaining power source, thus shutting down the HVAC system **10**.

Upon start up of the vehicle, the alternator or other charging device can be used to charge up the first and second power sources (if they are batteries) so that they are fully charged. In one embodiment of the present invention, the battery management controller **60** can also be used to connect the first power source (such as an auxiliary battery or bank of auxiliary batteries) during the start up of the vehicle in the situation where the second power source (such as the starter battery or bank of batteries) is too weak to start the vehicle, such as in the case where the starter battery is weakened because of very low exterior ambient temperatures.

Furthermore, the HVAC system can be a split system with a substantial portion of the components exterior to the vehicle's cab such that less interior space is taken up by the HVAC system. Also, the vehicle's existing evaporator and/or ducting can be used with the HVAC system for an easier installation process, improved efficiency, and quieter operation.

Alternative embodiments in which the power system **70** with the battery management controller **60** is utilized will now be discussed with reference to FIG. **10**. The power system **70** may comprise a first power source or battery **40**, a second power source or battery **42**, an electrical power generator **76** in an electrical generation system **44**, an electrical load **78**; a first regulator or converter **72**, a second regulator **73**, a third regulator **74**, a user interface **51**, and a battery management controller **60**. The first regulator or converter **72**, the second regulator **73**, the third regulator **74**, and the battery management controller **60** may constitute a power management module. The power management module may also include the user interface **51**, temperature and voltage sensors **63**, sensors for monitoring current flow to and from the first and second power sources, and/or the HVAC component controller **50**. The components of the power management module may be or may not be contained within a single housing.

In one exemplary embodiment, a truck may have seven batteries in which four batteries are connected in parallel to provide a high capacity first battery bank as the first power source **40** and the three remaining batteries are connected in parallel to provide a second, somewhat smaller battery bank as the second power source **42**. For the following discussion, the first power source **40** will be called the first battery (which may be a single battery or a plurality of batteries in a battery bank) and the second power source **42** will be called the second battery (which may be a single battery or a plurality of batteries in a battery bank). The first battery **40** can have a first battery voltage and the second battery **42** may have a second battery voltage that is different from the first battery voltage.

The first battery **40** and/or the second battery **42** may be connected to the first regulator **72**, the second regulator **73**, and temperature and voltage sensors **63**. Also, one of the first and second batteries is also connected to the vehicle starting system to provide power to start the engine of the vehicle, for example, by being connected to the engine starter **64**. In the embodiment of FIG. **10**, the first battery **40** may be, for example, one or more starter batteries which are used to start up the vehicle upon ignition. Accordingly, the first battery **40** may be connected to the engine starter **64**. According to one embodiment of the present invention, the first battery may be a lower quality battery than the second battery such that it may not be desirable to discharge the first battery to more than 20-30%. Alternatively or additionally, the first battery may be a secondary or auxiliary battery while the second battery may be the main battery of the vehicle. The second (main) battery can be connected to the first (secondary battery) for supplying current to the electrical load **78**.

The temperature and voltage sensors **63** may monitor the voltage and temperatures of the first and second batteries **40** and **42**. Additionally or alternatively, sensors for monitoring the current flow to and from the first and second batteries may be used. These sensors may be used to monitor the state of charge of the batteries so as to prevent the batteries from being over discharged.

The engine starter **64** is connected to one of the batteries so as to provide enough power to start the engine of the vehicle. The engine starter **64** may be electrically directly connected to the first battery, directly connected to the second battery, and/or directly connected to one of the first and second batteries while the other of the first and second batteries is connected to the engine starter through the second regulator or converter **73**. In FIG. **10**, the engine starter **64**, for example, is directly connected to the first battery **40** and is indirectly connected to the second battery **42** via the first battery **40** and the second regulator **73**.

The electrical power generation system **44** comprises an electrical power generator **76** configured to charge the first battery **40**, the second battery **42**, and/or run the electrical load **78**. Although the embodiment of FIG. **10** shows that the electrical power generator **76** is not directly connected to the load **78**, it is contemplated that the generator **76** may be directly connected to the load **78**. In one embodiment, the electrical power generator **76** is an alternator, such as a truck alternator, configured to be driven by the engine of the vehicle. The alternator may be configured such that, when the engine is on and running idle, the HVAC system should be able to run at maximum speed and load while the alternator provides maximum charging capacity for the batteries at the same time. For example, the alternator may be rated for 250A, 24 V or 500A, 12 V. In such an embodiment, the battery management controller **60** is configured to control the excitation of the alternator to control the alternator output voltage.

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The first regulator **72** may be a current regulator, which is connected to the electrical power generator **76** and to at least one of the first and second batteries **40** and **42**. The battery management controller **60** controls the current regulator **72** so as to regulate the amount of current flowing from the generator **76** to the at least one of the first and second batteries **40** and **42**. According to the embodiment of FIG. **10**, the first regulator **72** is connected to both the first and second batteries **40** and **42**, and thus may be controlled by the battery management controller **60** to regulate the amount of current flowing from the generator **76** to both the first and second batteries. In other words, the first regulator **72** may charge up the first battery **40**, charge up the second battery **42**, and/or run the components of the HVAC system **10** based on commands from the battery management controller **60**. The first regulator **72** may be a DC-to-DC converter, such as a buck DC regulator or a buck/boost DC regulator and selector.

The second regulator **73** may connect the first and second batteries **40** and **42** together to control the current flow between the first and second batteries. The regulator **73** may be a DC-to-DC converter, such as a buck/boost DC regulator and selector. The second regulator **73** may be a converter that is controlled by the battery management controller **60** to operate in a neutral mode, a first battery charging mode, or a second battery charging mode. In the first and second battery charging modes, the second regulator or converter **73** is configured to create a voltage difference between the first and second batteries. For example, in the first battery charging mode, the second regulator **73** is configured to adjust a voltage difference between the first and second batteries so as to cause current to flow from the second battery to the first battery to thereby charge the first battery, regardless of the respective charges of the two batteries. That is, current can flow from the second battery to the first battery even if the first battery may have a charge that is greater than, equal to, or less than the charge of the second battery. Thus, the battery management controller **60** coupled to the first and second batteries (for example, secondary and main batteries, respectively) is configured to adjust the system so that the first (secondary) battery is charged by the second (main) battery when a state of charge of the first (secondary) battery is below a predetermined threshold even when a state of charge of the second (main) battery is less than the state of charge of the first (secondary) battery.

In the second battery charging mode, the second regulator **73** is configured to adjust the voltage difference between the first battery and the second battery so as to cause current to flow from the first battery to the second battery to thereby charge the second battery, regardless of the respective charges of the two batteries. That is, current can flow from the first battery to the second battery even if the second battery may have a charge that is greater than, equal to, or less than the charge of the first battery. Thus, the battery management controller **60** coupled to the first and second batteries (for example, secondary and main batteries, respectively) is configured to adjust the system so that the second (main) battery is charged by the first (secondary) battery when a state of charge of the second (main) battery is below a predetermined threshold even when a state of charge of the first (secondary) battery is less than the state of charge of the second (main) battery.

In the neutral mode, the second regulator **73** is configured so that no current flows between the first and second batteries. For example, the battery management controller **60** may be configured to operate the second regulator **73** in the neutral mode so as to break the connection between the first and second batteries to prevent current from flowing between the

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two. Alternatively, the battery management controller **60** may be configured to operate the second regulator **73** in the neutral mode so as to adjust the voltage difference between the first and second batteries to prevent current from flowing between the first and second batteries.

The third regulator **74** may be a boost DC regulator connected to at least one of the first and second batteries **40** and **42** and to the load **78** (for example, one or more components of the HVAC system **10**). The boost converter raises the voltage being supplied to the load by the at least one of the first and second batteries **40** and **42**. In the embodiment of FIG. **10**, the boost converter **74** is connected between the second battery **42** and the load **78**. Thus, the boost converter of FIG. **10** raises the voltage being supplied to the load by the second battery **42**.

The electrical load **78** may be powered by at least one of the first battery **40**, the second battery **42**, and/or the electrical generator **76**. The load **78** may be components of the HVAC system **10** for either heating or cooling the compartment of the vehicle and/or other electrical power accessories, such as microwave ovens, televisions, stereos, refrigerators, etc.

The battery management controller **60** provides the following functions: (1) to monitor the first voltage of the first battery **40** and the second voltage of the second battery **42** and/or to monitor current flow to and from the first and second batteries **40** and **42**; (2) to control the operation of the second regulator or converter **73** to operate in either the neutral mode, the first battery charging mode or the second battery charging mode; (3) to control the first or current regulator **72** and the second regulator or converter to adjust the relative charging rates of the first and second batteries; (4) to control the third regulator or boost converter **74** to adjust the power being supplied to the load **78** from the at least one of the first and second batteries **40** and **42**; (5) to control the power system **70** to conduct an equalization charge of one of the first (secondary) battery and the second (main) battery using the other of the first and second batteries; (6) to control the electrical generator to raise an output voltage to an increased value greater than a normal output voltage in order to conduct an equalization charge on one of the first (secondary) battery and the second (main) battery; and/or (7) to control the first or current regulator **72** so as to increase the amount of current flowing from the generator to the one of the first (secondary) battery and the second (main) battery.

The battery management controller **60** may also fulfill a variety of other different purposes including: (1) maximizing the electrical power available for use by the HVAC system; (2) ensuring that sufficient electrical reserve power is available to start the engine; (3) tracking historical use (charge and discharge) of all connected batteries; (4) determining the current state of charge of all connected batteries; (5) determining the current end-of-life status of all connected batteries irrespective of their respective charge level; (6) ensuring that the charge and discharge cycles of all connected batteries are consistent with the user's preferred compromise between battery longevity and available stored energy; and (7) preventing the overloading of the battery charging system.

The battery management controller **60** may comprise a control logic circuit **66** and a memory **67**. The battery management controller **60** carries out its function by being connected to the voltage and temperature sensors **63**, the first regulator **72**, the second regulator **73**, the third regulator **74**, the electrical power generation system **44**, a user interface **51** (which may comprise a display **310** and one or more input devices **312**), and the power management/HVAC component controller **50**.

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The memory 67 of the battery management controller may be any suitable storage medium, such as a ROM, a RAM, an EEPROM, etc. The memory 67 is used to store a plurality of data to be utilized by the battery management controller 60 when controlling the components of the power system 70. For example, the memory 67 may be used to log historical data obtained during previous charge and discharge cycles, such as voltage and temperature levels, and use the historical data to modify the permitted depth of discharge to ensure the completeness of future charge cycles. For example, to ensure that the batteries are fully recharged between cycles to prevent premature sulfation and destruction of the batteries, the battery management controller may monitor and store the time and power levels of the batteries during the discharge and recharge cycles. This historical data may verify that, in a typical discharge and re-charge cycle, sufficient time and power is available to fully recharge the batteries. If there is not sufficient time and power to fully recharge, the control logic circuit 66 may respond by raising the minimum battery cut-off voltages thereby reducing the total amount of power which may be drawn from the batteries. In other words, the battery management controller 60 may be configured to be self-learning which allows the controller to maximize the battery replacement life by monitoring the first and/or second power sources such that they are not excessively discharged (i.e., drained) and such that they are not discharged to a level that does not allow the power source to be fully recharged during the typical engine run time. For example, consider that a power source might be a battery in which the battery may be safely discharged to a level X. Thus, the level X may be the predetermined amount value during the determination of whether the power source should be connected to the HVAC system. However, if the run cycle of the engine was too short to allow the battery to fully recharge during the engine run after the battery had been partially discharged, the battery would still be prematurely destroyed because failure to fully recharge a battery is just as harmful as discharging it too deeply (or draining the charge too much). To prevent the premature destruction of a battery due to it not being fully recharged, the battery management controller 60 may monitor the battery charge in the power source to determine if the battery was fully recharged. If the battery was not, then the controller 60 may be configured to “learn” during the next operation where the power source is connected and the engine is turned off such that the battery should be less deeply discharged, i.e., the battery should be discharged to a level Y, which is greater than the level X. Then, the level Y may be the predetermined amount value during the determination of whether the power source should be connected to the HVAC system. In more simplified terms, if a battery (such as the first battery 40 or the second battery 42) can only be recharged at a certain charge rate and if a user has a tendency to run the engine of the vehicle for an amount of time shorter than is necessary to fully charge the battery when it is discharged to a certain level, this information is used by the battery management controller 60 to modify the allowed amount that the battery can be discharged. Thus, with the modified level of allowed discharge, the battery will be more likely to be fully charged after the engine has been run for that user’s typical amount of time.

The memory 67 can also store data that is useful in determining the current state of charge of the batteries. For example, in a more conventional HVAC system, the measurement of the battery voltage under load is used to determine the state of charge. While this method is low in cost and easy to implement, it is also highly inaccurate. The voltage may be used to accurately determine the state of charge but only when

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such measurements are taken in conjunction with temperature and only after the battery has been “at rest” (i.e., unloaded) for a period or time (typically over one hour). However, the battery management controller 60 of FIG. 10 may use multiple sources of historical data (stored in the memory 67) and real-time data to more accurately determine the current amount of stored energy available for use. Additionally, the battery management controller 60 allows highly accurate “resting voltage” measurements of the state of charge to be made of the power reserve and to be stored even when portions of the battery power supply are still in use.

Additionally, the memory 67 may be connected to an input/output device 68 which allows the memory 67 to transmit data collected by the battery management controller 60 to the input-output device 68. The input/output device 68 can be any memory storage medium, including flash drives, such as USB memory sticks or CompactFlash cards, or hard drives. The battery management control 60 may be configured so that a vehicle user uses the interface 51 to sample system data, such as voltage and temperature levels, or any other data which may be sampled by the battery management controller 60. The input/output device 68 is useful when a user instructs the battery management controller 60 through the interface 51 to sample the system data at a preferred sampling rate (e.g., every 10 seconds). The data is stored in the memory 67, and transmitted to the input/output device 68. The input/output device 68 is preferably a very large memory bank so several months worth of data can be recorded.

The control circuitry 66 of the battery management controller 60 may comprise the necessary hardware, software, or other mechanisms necessary to carry out the functions to which it was designed.

The user interface 51 may include a display 310 and input devices 312. The display 310 of the user interface 51 may provide a user, such as a vehicle occupant, information related to the status of the HVAC system 10 and/or the power system 70. The display may include one or more of an alphanumeric display, a graph, or the like. For example, the display may include the vehicle’s interior ambient temperature, the exterior ambient temperature, the circulation blower speeds, the usage of the power source or sources supplied to the HVAC system 10, and warning messages, etc. In one example, if the first power source and the second power source are batteries, the display may show the current approximate battery charges for each power source to the vehicle occupant.

One or more input devices 312 may also be a part of the user interface. The input devices may be one or more of a keyboard, a control panel, or the like, so that the vehicle occupant may input user preferences for the operation of the HVAC system 10 and the power system 70. For example, the user preferences may include the operating mode of the HVAC system such as off, heating, and cooling modes of operation. Also, the input device 312 of the user interface may allow a user, such as a vehicle occupant, to select the operating mode of the second regulator or converter 73, for example, the neutral mode, the first battery charging mode, or the second battery charging mode. Additionally, the interface 51 can include a programmable timing device 314 so that the operating mode of the HVAC system 10 is determined based on time values instead of user inputs. For example, the timing device 314 may be programmed so that the heating is turned off at a certain time (e.g., 6:00 a.m.) or after a certain amount of time (e.g., 6 hours).

Below is a discussion of the processes that occur during the accessory run mode when the batteries are discharging when

in the engine is turned off, the engine start-up mode, and recharge mode when the batteries are being recharged when the engine is turned on.

The process that the power system including the battery management controller undergoes during an accessory run (discharging) mode is provided in FIG. 11(a). The discharging of the first and/or second batteries occurs when the engine is turned off and an accessory or a plurality of accessories is turned on as shown in step 1402. Although the foregoing discussion talks of only one accessory being powered, it is understood the same discussion applies to when a plurality of accessories are being powered. According to one example the accessory may be the HVAC system 10 for heating or cooling the compartment of the vehicle. The battery management controller 60 ("BMC") determines a minimum acceptable state of charge for both batteries based on preset base limits, historical charge/discharge levels, priority battery conditions, user inputs, and temperature as shown in step 1404. In step 1406, the battery management controller 60 through its control circuit 66 determines the state of charge and condition of the first and second batteries by using the current voltage and temperature of the batteries from data received by the voltage and temperature sensors 63 and optionally the historical data stored in the memory 67 of the controller 60. The battery management controller then determines if the first battery has sufficient charge and if the second battery has sufficient charge.

If neither battery has sufficient charge, the process proceeds to step 1408 in which the user is notified that there is insufficient battery charge to run the accessory. The accessory is turned off, and the process ends at step 1409.

If only the first battery has sufficient charge, the process proceeds to step 1410 in which the battery management controller 60 selects the first battery 40 as a power source and the accessory is operated at step 1412. The current from the first battery 40 runs through the second battery 42 as it travels from the first battery 40 through the third regulator 74 to the load 78. As the accessory is running, the state of charge for the first battery is monitored by the controller 60 at step 1414, and if the state of charge of the first battery falls below a predetermined level, the first battery is deselected at step 1416.

At step 1418, the second battery is monitored to determine if it has sufficient state of charge to run the accessory. Although the second battery did not have sufficient charge in step 1406, the charge of the second battery may have replenished after sitting around for a while. In the event that the second battery replenishes sufficiently to be used as a power source for the accessory, the second battery can be used to power the accessory.

At step 1420, there is a comparison between the projected accessory run time (based on state of charge of the second battery and/or user input) and the historical run time. For example, the power draw (current) from the HVAC system 10 is monitored and the rate of decline in the battery is noted. The power draw and rate of decline is compared to historical data to determine the approximate state of sulfation of the battery plates and from this comparison, the approximate condition of the battery is deduced. Under a given load, the voltage of batteries in poor condition will decline faster than batteries in good condition. Consequently, it may be predicted that batteries in poor condition will have less total stored energy even though the actual voltage at any given time may be the same. In one example, data may be collected related to the maximum battery discharge and/or the average battery discharge during an operation cycle of the batteries. This data may be compiled over time such that a history of the maximum and/or

average battery discharge is stored in the memory 67 in the battery management controller 60.

As another example, user preferences which are inputted using the user interface 51 are also factors that influence the extent to which the batteries 40 and 42 will be allowed to be discharged. One example is the battery replacement life. Battery replacement life is related to the depth of the discharge of the power source as well as the rate of discharge, i.e., a function of the minimum battery voltage adjusted by the load. For example, a lightly loaded battery which is consistently discharged to 11.8 V may only last through 100 charge/recharge cycles while a heavily loaded battery that was consistently discharged to 11.8 V might last 200 charge/recharge cycles. If a user preference is set for a long battery life, the batteries will be less deeply discharged and will last longer. However, because less stored energy will be available for use, more batteries will need to be carried to supply a given amount of cooling or heating than would be the case if a shorter battery life (and more deeply discharged batteries) were selected.

Based on the comparison of the projected accessory run time and the historical run time, the battery management controller 60 will send a signal to the HVAC component controller 50 so as to adjust the running of these components so as to enable the operation of these components for the full desired amount of time, as shown in step 1422. As the voltage of the second battery is being discharged, in step 1424, the battery management controller will continue to monitor the state of charge of the second battery, and send signals to the HVAC component controller so as to adjust the running of the accessories based on the current state of charge.

With continued operation of the HVAC system 10, the voltage of the first battery 40 continues to decline. The battery management controller logic circuit re-analyzes the battery 40 by comparing real time data on the power draw, the temperature and the rate of voltage decline with the stored historical data and the user input preferences to determine the amount of stored energy available.

A determination is made of the minimum system disconnect voltage, i.e., the battery cut-out voltage. From this determination, a calculation is made of the estimated time to battery depletion for the first battery and this estimated time information is communicated to the HVAC component controller 50. Because the estimated time information is based on both static data (such as historical and user input) and real-time data (such as current voltage levels and temperatures), a change in the performance, the system load or the ambient conditions during the operation of the HVAC system 10 may change the estimated time information which may increase or decrease the calculation of the available system run time. As long as there is sufficient voltage, the battery management controller will continue to have the second battery power the accessory and monitor the second battery's voltage level (and/or the current flow to and from the battery). However, the power may eventually be depleted from the second battery 42 to the point where the voltage falls to the level calculated by the control logic circuit to be the minimum allowed, i.e., the battery cut-out voltage, and disconnect the second battery 40. Once the state of charge of the second battery falls below the minimum allowed level, the process proceeds to steps 1408 and 1409 in which the user is notified via the user interface of the insufficient battery charged to run the accessory and the accessory is turned off.

Referring back to step 1406, if only the second battery is determined to have sufficient charge to run the accessory, the process proceeds to step 1426 in which the accessory starts running while only using the second battery as the power



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source. As the accessory is running, the state of charge for the second battery is monitored by the controller 60 at step 1414. Step 1416 does not really take place because the first battery was never selected as the power source for the accessory so there is no need to deselect it. Thus, from step 1414, the process may then proceed to step 1418. At step 1418, the second battery is monitored to determine if it has sufficient state of charge to run the accessory.

At step 1420, there is a comparison between the projected accessory run time (based on the state of charge of the second battery and/or user input) and the historical run time, as previously described. Based on the comparison of the projected accessory run time and the historical run time, the battery management controller 60 will send a signal to the power management/HVAC component controller 50 so as to adjust the running of these components so as to enable the operation of these components for the full desired amount of time, as shown in step 1422. In step 1424, the battery management controller will continue to monitor the state of charge of the second battery, and send signals to the HVAC component controller to adjust the running of the accessories based on the current state of charge. Once the state of charge of the second battery falls below a predetermined level, the process proceeds to steps 1408 and 1409 in which the user is notified via the user interface of the insufficient battery charged to run the accessory and the accessory is turned off.

Referring back to step 1406, if both the first and second batteries are determined to have sufficient charge to run the accessory, the process proceeds to step 1428 in which the accessory started running while both batteries are used as the power source. As the accessory is running, the state of charge for each battery is monitored by the controller 60 at step 1414. As the accessory is running, the state of charge for the first battery is monitored by the controller 60 at step 1414, and if the state of charge of the first battery falls below a predetermined level, the first battery is deselected at step 1416. At step 1418, the second battery is monitored to determine if it has sufficient state of charge to run the accessory.

At step 1420, there is a comparison between the projected accessory run time (based on state of charge of the second battery and/or user input) and the historical run time, as previously described. Based on the comparison of the projected accessory run time and the historical run time, the battery management controller 60 will send a signal to the power management/HVAC component controller 50 so as to adjust the running of these components so as to enable the operation of these components for the full desired amount of time, as shown in step 1422. In step 1424, the battery management controller will continue to monitor the state of charge of the second battery, and send signals to the HVAC component controller to adjust the running of the accessories based on the current state of charge. Once the state of charge of the second battery falls below a predetermined level, the process proceeds to steps 1408 and 1409 in which the user is notified via the user interface of the insufficient battery charged to run the accessory and the accessory is turned off.

The process that the power system including the battery management controller undergoes during an engine start mode is provided in FIG. 11(b). Initially, the engine is turned off as shown in step 1450. An operator tries to start the engine at step 1452. At the start up of the engine, a heavy electrical load is applied to the first battery 40 causing the voltage of the first battery 40 to drop. The amount of drop depends on the condition, the state of charge, and the temperature of the first battery 40 as well as the engine itself. Thus, there is a chance that under certain adverse conditions, the voltage drop will be so severe as to prevent the engine from starting unless addi-

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tional electrical power is made available. Alternatively or additionally, the discharge of the first battery may be at such a level that there is insufficient voltage for the engine starter. For example, the first battery may be already 80% discharged or even dead before applying the heavy electrical load. If the voltage or state of charge of the first battery is insufficient to start the engine, the battery management controller provides a "start assist" function in which the second battery is used to charge the first battery up to a level sufficient to start the engine.

At step 1454, the battery management controller 60 monitors the voltage or state of charge of the first battery 40 (or the current flow to and from the battery) to determine if it falls below a preset limit, for example, a voltage level that would prevent the first battery 40 from starting the engine. If the voltage of the first battery 40 does not fall below the preset limit, no further action is needed to be taken by the battery management controller 60 in regard to starting the engine, as indicated in step 1456, because there is sufficient voltage or charge in the battery to start the engine. Thus, the engine is started. If the voltage of the first battery 40 falls below the preset limit, but the engine starts anyway, as indicated in step 1458, no further action needs to be taken by the battery management controller 60 in regard to starting the engine, as indicated in step 1456. However, the battery management controller may command that the first battery be recharged, as will be discussed later.

If the voltage of the first battery 40 falls below the preset limit, and the engine fails to start, as indicated in step 1460, the process proceeds to step 1462 wherein the battery management controller 60 notifies the user that the charging of the first battery is in process. The user may be notified through the display 51 and/or through any other suitable audio, visual, or tactile indicator. At step 1464, the battery management controller 60 then controls the second regulator or converter 73 to boost the voltage from the second battery 42 and use it to charge the first battery 40 (the first battery charging mode). This boosting is accomplished by the battery management controller adjusting a voltage difference between the connecting first and second batteries to cause current to flow from the second battery to the first battery to thereby charge the first battery. In a simplified example, each battery is connected to a DC-to-DC converter of the buck/boost type as a load/source. The determination of whether the first battery is a load (receiving current) or a source (sending current) depends upon the duty cycle of the switching transistor associated with it. Likewise, the determination of whether the second battery is a load (receiving current) or a source (sending current) depends upon the duty cycle of the switching transistor associated with it. The duty cycles of these switching transistor is determined and controlled by the battery management controller 60.

At step 1468, the state of charge of the first battery 40 is monitored and determined by the battery management controller 60. If the first battery 40 has sufficient charge, the process proceeds to step 1470 wherein the user is notified by the display 51 and/or any other suitable audio, visual, or tactile indicator to retry starting the engine. From step 1470, the process proceeds back to step 1452. If the first battery 40 does not have sufficient charge, the recharging of the first battery 40 with the voltage of the second battery 42 continues but the battery management controller 60 also monitors the voltage of the second battery 42 (or the current flow to and from the battery). If the second battery 42 has sufficient charge, the recharging continues as indicated in step 1472 and



the state of charge of the first battery 40 is monitored and determined by the battery management controller 60 as indicated in step 1468.

If at any point, during the recharging, the battery management controller 60 determines that the second battery does not have sufficient charge to continue the recharging, the process proceeds to step 1470 wherein the user is notified by the display 51 and/or any other suitable audio, visual, or tactile indicator to retry to start the engine. From step 1470, the process proceeds back to step 1452. Optionally, after a predetermined number of iterations, if the first battery does not gain sufficient charge to start the engine and the second battery does not have sufficient charge to recharge the first battery, the user can be notified by the display 51 and/or any other suitable audio, visual, or tactile indicator to cease attempting to start the engine.

To provide a more concrete example of the start assist function, if both the first and second batteries, for example, are each discharged 80% and neither battery alone is suitable to start the engine. The battery management system issues commands such that the last 20% charge left in the second battery 42 is channeled through the second regulator 73 into the first battery so as to charge up the first battery 40. Even though the charge of the first battery 40 will become greater than the charge of the second battery during the process of charging up the first battery, the charging up process will still continue until the first battery is charged up to a level so that the first battery can be used to start the engine. For example, the first battery 40 will continue to be charged if the first battery is charged to 25% while the second battery is depleted down to 15%. If the engine can start with a battery charged to 30%, the charging process will continue to this point, even though the second battery may be depleted down to 10%. In this example, the second battery is used only to charge the first battery. This charging process may be more advantageous than merely directly coupling the first and second batteries to each other and then directly connecting the coupled batteries to the starter. For instance, in an example where the first battery is depleted and the second battery is fully charged, if both batteries are connected to each other, the second battery may be uncontrollably drained by the first battery instead of being used to start the engine.

The process that the power system including the battery management controller undergoes during a recharging mode is provided in FIG. 11(c). Upon the start up of the engine, a charge power source, such as an electrical power generator 76 or alternator, is activated, as indicated in step 900. The battery management controller 60 determines, in step 902, the state of charge of the first and second batteries, and then proceeds to step 904.

At step 904, there is a determination of whether there has been any user input provided from the user interface 51. For example, the user interface may be configured to allow a vehicle occupant to select the operating mode of the second regulator or converter. For example, if the user selected the first battery to be charged first, the process proceeds to step 905 in which the battery management controller controls the first regulator 72 to regulate the amount of current flowing from the generator so that it charges the first battery before the second battery. Similarly, if the user selected the second battery to be charged first, the process proceeds to step 905 in which the battery management controller controls the first regulator 72 to regulate the amount of current flowing from the generator so that it charges the second battery before the first battery. However, as the selected battery charges up, a situation may occur in which the voltage of the selected battery being charged up by the power generator exceeds the

voltage of the unselected battery. In such an instance, to prevent the current from flowing through the selected battery and into the unselected battery, the battery management controller 60 may control the second regulator 73 so that it is in a neutral mode to prevent any current from flowing between the two batteries or in a mode to ensure that only the selected battery is being charged.

Once the selected battery reaches a predetermined threshold such that it can be considered suitably charged, the process can proceed to step 906 in which the remaining battery is recharged. In this instance, the first regulator 72 may be controlled by the battery management controller 60 to only charge up the remaining controller. Alternatively, the first regulator 72 may be controlled to charge up both batteries but the second regulator 73 may be controlled such that the current will flow through the suitably charged battery and into the remaining battery, which may result in the suitably charged battery being "topped off."

As an alternative to steps 905 and 906, the user may select that both the batteries be charged at the same time. In this instance, the user may select the charging rates upon which each battery should be charged. For example, if the user wishes to have both batteries charged at the same rate, the first and second regulators 72 and 73 may be controlled by the battery management controller 60 such that the same amount of current will flow into each battery, regardless of their respective states of charge. In addition, if the user wishes to have the batteries both be charged at different charging rates, the first and second regulators 72 and 73 may be controlled such that these rates can be accomplished by controlling the amount of current flow to each battery from the power generator and the amount of current flow from one battery to another. Thus, the battery management controller can control the first and/or second regulators to increase the amount of current flowing from the generator to one of the first and second batteries. Whether charged sequentially or concurrently, the power generator continues to recharge the batteries until they are both above a suitable respective threshold at which the recharging may cease or until the engine is stopped.

Referring back to step 904, if there is no user input, the battery management controller may determine the charging rates of the first and second batteries based on a level of charge. In one example, one battery (such as the first battery used as a starter battery) may be selected to be charged first over the other if it falls below a certain threshold (step 908), and then the remaining battery is charged after the selected battery is suitably charged (step 910). Alternatively, both batteries may be charged at different charging rates based on the level of charge of each battery or other similar criteria. Whether charged sequentially or concurrently, the power generator continues to recharge the batteries until they are both above a suitable respective threshold at which the recharging may cease or until the engine is stopped.

FIG. 12 shows another embodiment of the power system 70'. The configuration of the power system 70' is the same as the configuration of FIG. 10 with the following exceptions. First, the first battery 40' is not a starter battery but merely an auxiliary bank of batteries while the second battery 42' is the main bank of batteries. In addition, the third regulator has been removed and the power from the second battery is directly channeled into the load 78, such as the variable-speed HVAC system.

FIG. 13 shows another embodiment of the power system 70". The configuration of the power system 70" is the same as the configuration of FIG. 10 with the following exceptions. First, the first battery 40' is not a starter battery but merely an auxiliary bank of batteries while the second battery 42' is the

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main bank of batteries. In addition, the third regulator has been removed and the power from the first and second batteries is fed into the load **78** via the second regulator **73'**. The second regulator **73'** acts as a buck/boost DC-to-DC converter and as the boost regulator to the load **78**. The second regulator then permits current to flow between the first and second batteries as described in relation to the second regulator **73** in FIG. **10**, but also current can flow from the first and/or second battery to the load **78** based on the duty cycle of the switching transistor associated with the respective first battery, second battery, and load **78**.

FIG. **14** shows another embodiment of the power system **70'''**. The configuration of the power system **70'''** is the same as the configuration of FIG. **13** with the following exception. Instead of an electrical power generator **76** comprising a single alternator, the power generator comprises two charging devices **82** and **84**. Each charging device may be, for example, a wind turbine generator, a hydro turbine generator, a diesel generator, a gas turbine generator, an alternator, an AC source, one or more solar panels or any other power source. Both charging devices are connected to the first regulator **73**.

FIG. **15** shows another embodiment of the power system **70''''**. The configuration of the power system **70''''** is the same as the configuration of FIG. **13** with the following exceptions. First, instead of an electrical power generator **76** comprising a single alternator, the power generator comprises a motor/generator **86**. Second, the first regulator **72'** acts as a buck/boost DC-to-DC converter from the first and second batteries to the motor generator **86**. The first regulator then permits current to flow from the generator to the first and second batteries as described in relation to the first regulator **72** in FIG. **10**, but also current can flow from either or both the first and second batteries to the motor **86** based on the duty cycle of the switching transistor associated with the respective first battery, second battery, and motor/generator **86**. The battery management controller **60** may determine what mode the motor/generator is in, and whether power from the first and/or second batteries are required to power the motor/generator when in the motor mode.

In yet another embodiment of the power system, the configuration of the power system may be the same as the configuration of FIG. **10** with the following exception. One of the batteries is only charged by the other battery. For example, the first battery may be charged only by the second battery or the second battery may be only charged by the first battery. The configuration can be accomplished by removing the electrical connection from the first regulator to either one of the first and second battery. Alternatively, only one of the batteries is attached to the electric power generator **76** without even including the first regulator **72**. In yet another alternative, the configuration may be the same as FIG. **10** but that the first and second regulators **72** and **73** are always controlled by the battery management controller **60** so that one of the batteries is only charged by the other battery.

Because the first and second power source may be batteries, they may benefit from a periodic controlled overcharge, which is often referred to as an equalization charge. The equalization charge mixes up the electrolyte, which tends to stratify or separate into overlapping layers of acid and water and also helps remove some sulfate deposits. During an equalization charge, the battery is charged well after the point at which the battery would be normally considered to be fully-charged while avoiding excessive battery heating or electrolyte boil-off. For example, a battery voltage is allowed to rise to a high voltage (such as approximately 16, 17, or more volts for a 12 volt battery), where it is maintained for a length of time (for example, up to 7, 8, 9 or more hours) by

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adjusting of the charging current. Of course, it should be kept mind that if the first or second battery is a battery bank, the equalization charge would apply across the battery bank.

According to one embodiment of the present invention, the power generator **76** (such as an alternator) may be used to provide an elevated voltage for the equalization charge for one of the first (secondary) battery and the second (main) battery. For example, based on user input from the user interface **51**, the battery management controller **60** may be configured to control the power system **70** to conduct an equalization charge of one of the first (secondary) battery and the second (main) battery using the electrical generator to raise an output voltage to an increased value greater than the normal output voltage in order to conduct an equalization charge of one of the first (secondary) battery or the second (main) battery. To achieve this rise in output voltage, the battery management controller **60** may adjust the excitation of the electrical generator.

According to another embodiment of the present invention, one battery may be used to elevate the charge of the other battery so that the other battery undergoes an equalization charge. For example, based on user input from the user interface **51**, the battery management controller **60** may be configured to control the power system **70** to conduct an equalization charge of one of the first (secondary) battery and the second (main) battery using the other of the first (secondary) battery or the second (main) battery by controlling the second regulator **72** such that a voltage difference is sufficiently created between the first and second batteries to cause a flow of current from one battery to the other such that the other battery undergoes an equalization charge.

Next, the power management/HVAC component controller **50** will be described. The power management/HVAC component controller **50** controls the components of the HVAC system **10**, and works in conjunction with the battery management controller **60**. The purpose of the power management/HVAC component controller **50** is to: (1) communicate to the user via the user interface; (2) monitor safety functions and initiate appropriate responses; (3) maximize the operational efficiency of the HVAC system by optimizing the speed of the condenser and evaporator fans and the speed of the compressor motor according to ambient conditions and user preferences; (4) regulate the speed of the condenser fans to control the condenser temperature thereby obtaining the best compromise between increased fan motor power consumption and increased compressor motor power; (5) regulate the speed of the evaporator fan proportionate to the temperature differential between the user temperature set point and the actual ambient temperature; and (6) regulate the speed of the compressor motor to maintain the desired evaporator temperature.

The power management/HVAC component controller **50** carries out its function by being operationally connected to the battery management controller **60**, the user interface **51** (which includes a display **310** and one or more inputs **312**), a plurality of sensors, and the operational components of the HVAC system as show in FIG. **16**. The plurality of sensor detects a variety of parameters including: the vehicle's interior ambient temperature detected by a temperature sensor **304**, the humidity of the vehicle's compartments by using a humidity sensor **307**, and noise and/or vibration from one or more noise or vibration sensors **308**.

As to the operational components of the HVAC system, the power management/HVAC component controller **50** may run the motor **12** that drives the compressor **14**; the circulation blowers that blow the temperature-controlled air into one or more designated compartments (such as the vehicle compart-

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ment 23 and/or the sleeping compartment 27); the heaters for the heating system (such as the air heaters 272 and 274 from FIG. 1 or the heater 180 from FIG. 2); and the control doors (if applicable) for the regulation of the temperature. Additionally the power management/HVAC component controller 50 may also switch any control valves to control the flow of refrigerants (such as the valves 28 and 29 from FIG. 1 or the valves 184 and 184 from FIG. 2). In one embodiment, the motor 12 of the compressor 14 may be controlled by the power management/HVAC component controller 50 using a closed loop proportional, integral, derivative (PID) control. Similarly, the power management/HVAC component controller 50 may also control the fan speed of the circulation blowers 210 and 212 via a pulse width modulated (PWM) PID control loop that is independent of the control for the compressor.

In one embodiment, the power management/HVAC component controller 50 may modulate the speed of the motor 12, and thus may modulate the capacity of the compressor 14 driven by the motor 12. The modulation of the compressor may range between an upper compressor capacity and a lower compressor capacity. The compressor capacity may vary depending on the compressor capacity required to maintain the evaporator 22 or 26 at the evaporator temperature  $T_E$  as commanded by the control logic circuit 66.

In one exemplary embodiment of the present invention, the power management/HVAC component controller 50 ("HCC") may work as described below with reference to FIG. 14. The power management/HVAC component controller 50 receives a signal from the user interface 51 to begin operation at step 702. Commands are sent to the battery management controller 60 ("BMC") from the power management/HVAC component controller 50 to supply power to the HVAC system 10 at step 704. The user interface 51 is polled for the user preference settings, such as the mode of operation, the location of temperature control, and the desired set point temperature  $T_{sp}$ . Also the ambient temperature  $T_a$  is read from the temperature sensor 304 at step 706.

If the user preference is for the "cooling" mode, the process is sent to step 708 where a command is issued to start all fans of the circulation blowers 210, 212 and the motor 12 of the compressor 14 to a minimum speed. At step 710, the compressor speed is then commanded to bring and hold the evaporator 22 to a predetermined evaporator temperature  $T_E$  if the vehicle compartment is being cooled or to bring and hold the evaporator 26 to a predetermined evaporator temperature  $T_E$  if the sleeping compartment is being cooled. At step 712, the fans of the condenser 16 are commanded to bring and hold the condenser 16 to a predetermined condenser temperature  $T_C$ .

If the user preference is for the "heating" mode, a command from the power management/HVAC component controller 50 is issued at step 714 to start the fans of the circulation blowers of the evaporator 22 or 26. The electric heating element 270 or 274 is commanded at step 716 to a power level (via PWM control) proportionate to the fan speed of the circulation blowers of the evaporator 22 or 26.

With the HVAC system 10 now running in either the heating or cooling mode, the battery management controller 60 is polled for an estimate of the run time based on the present power draw and stored energy available for use in step 718. As step 720, the estimated run time is compared to the desired run time which was programmed into the user settings by the user using the user interface 51. The power management/HVAC component controller factors the difference between the estimated and desired run times into planning the output of the HVAC system 10 to ensure that sufficient power is available for the duration of the heating or cooling period (also called the "run time plan"). Based on the run time plan,

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the power management/HVAC component controller 50 may increase or decrease the average capacity of the HVAC system periodically throughout the cycle. In particular, if the amount of heating (steps 726 and 736) or the amount of cooling (steps 726, 728, and 730) would require too much power to be drawn from the power source(s), the highest capacity of the HVAC system 10 possible would be employed which would still allow the battery management controller to supply power through the entire operational period. The highest capacity possible may be obtained through a combination of settings which would offer the best efficiency for the prevailing conditions.

At step 722, a variety of measurements are taken at step 722 so as to ensure that the HVAC system runs efficiently with its limited power supply. These measurements include the actual ambient temperature of the vehicle's interior  $T_a$ , the evaporator temperature  $T_E$ , and the condenser temperature  $T_C$ . At step 722, temperature sensors on the evaporator measure the evaporator temperature  $T_E$ , temperature sensors on the condenser measure the condenser temperature  $T_C$ , sensors in the vehicle and/or sleeping compartments measure the ambient temperature  $T_a$ , and the user inputs the desired ambient temperature or the set point temperature  $T_{sp}$  via the user interface 51.

For efficient operation of the HVAC components in either the cooling or heating mode, a calculation is made at step 724 in which a difference  $\Delta$  between the ambient temperature  $T_a$  and the set point temperature  $T_{sp}$  is determined. Then, the circulation blowers at the evaporator 22 or 26 are commanded to a speed proportionate to the difference  $\Delta$  at step 726. The determination of an appropriate fan speed for the blowers at the evaporator based on a given  $\Delta$  may be based on any one of a number of methods known in the art such as tabular formulations or computer models.

The air blown into the vehicle and/or sleeping compartments affects the ambient temperature of the compartment; thus with continued operation of the HVAC system, the difference ( $\Delta$ ) between the ambient temperature  $T_a$  and the set point temperature  $T_{sp}$  begins to decrease. As the ambient temperature  $T_a$  nears the set point temperature  $T_{sp}$ , the power management/HVAC component controller 50 reduces the fan speed of the circulation blowers at the evaporator 22 or 26 proportionately based on  $\Delta$ , as seen in step 726. If the system is in the cooling mode, the reduced air flow over the evaporator 22 or 26 causes the evaporator temperature  $T_E$  to fall. In response, the power management/HVAC component controller 50 adjusts the speed of the motor 12 that drives the compressor 14 to maintain the desired evaporator temperature  $T_E$  at step 728. Similarly, the changing capacity of the evaporator 22 or 26 also changes the temperature of the condenser  $T_C$ . Again, the power management/HVAC component controller 50 adjusts the fan speed of the condenser 16 so as to maintain the desired condensing temperature  $T_C$  at step 730. However, the settings for the circulation blowers, the compressor, and the condenser (which are set in steps 726, 728, and 730 respectively) are subject to the highest possible capacity of the HVAC system based on the run time plan. Thus, if too much power would be drawn by these components while running at the most efficient operation, the settings of these components would be adjusted so as to allow the system to run for the desired run time while operating as close as possible to the most efficient operation determined by  $\Delta$ .

The process continues to step 732 where the HVAC component controller receives data from the battery management controller 60 about whether there is sufficient power being supplied. If there is sufficient power (the "YES" path), the process returns to step 718 and the process is repeated. If there

is insufficient power (the “NO” path), the operation of the HVAC system is terminated at step 734.

If the HVAC system is operating in heating mode rather than the cooling mode, the power management/HVAC component controller 50 alters the PWM cycle of the resistive heating elements 270 or 274 to match the changing fan speed of the circulation blower at the evaporator 22 or 26. In this way, the temperature of the discharged air remains constant. Thus, step 736 is carried out in FIG. 17 instead of steps 728 and 730. Similar with the cooling operation, the settings for the circulation blowers and the heater (which are set in steps 726 and 736 respectively) are subject to the highest possible capacity of the HVAC system based on the run time plan. Thus, if too much power is being drawn by these components while running at the most efficient operation, the settings of these components may be adjusted so as to allow the system to run for the desired run time while operating as close as possible to the most efficient operation determined by  $\Delta$ . For example, the settings of the circulation blowers may be lowered to a level that permits operation during the entire desired run time while still operating as close as possible to the settings for the most efficient operation based on  $\Delta$ .

Other system parameters may be used to control the motor-driven compressor 14 and the circulation blowers 210 and 212. For example, the power management/HVAC component controller 50 may also monitor humidity of the vehicle's compartments by using a humidity sensor 307. If the humidity of the compartments is above a predetermined threshold (which may be set by the vehicle occupant), the power management/HVAC component controller 50 may control the compressor 14 to speed up (up to but not exceeding the upper compressor capacity) and the circulation blowers 210 and 212 to slow down.

Furthermore, one or more noise or vibration sensors 308 may be used to determine the level of noise or vibration of the HVAC system 10. Once the signal is sent to the power management/HVAC component controller 50, the controller 50 determines whether there is a need to speed up or slow down the compressor and/or blower, and to control the compressor and/or blower accordingly.

The use of one or more system parameters, such as the evaporator temperature, the humidity, the exterior ambient temperature, the vehicle's interior temperature, etc. to control the compressor and blower capacities may be accomplished by monitoring the one or more system parameters and using a program in the power management/HVAC component controller 50 that was compiled using, for example, a multivariate model known in the art.

Other system parameters may also be provided to the power management/HVAC component controller 50, which may allow the power management/HVAC component controller 50 to detect faults within the HVAC system. For example, performance and safety functions are monitored and an appropriate response by the power management/HVAC component controller 50 may be initiated, such as shutting down the system in the event of the overheating of the motor 12 of the compressor 14.

Additionally, sensor measurements utilized by the power management/HVAC component controller 50 may be stored in the memory 67 of the battery management controller 60. For example, the vehicle's interior ambient temperature detected by the temperature sensor 304, the humidity of the vehicle's compartments detected by humidity sensor 307, and noise and/or vibration levels detected by noise or vibration sensors 308 may all be transferred by the power management/HVAC component controller 50 to the memory 67 of the battery management controller 60. Additional measurements

which can be stored in memory 67 include the actual ambient temperature of the vehicle's interior  $T_a$ , the evaporator temperature  $T_E$ , and the condenser temperature  $T_C$ , the evaporator measure the evaporator temperature  $T_E$ , condenser temperature  $T_C$ , ambient temperature  $T_a$ , and set point temperature  $T_{sp}$ .

The input/output device 68 containing the system's historical data collected by the power management/HVAC component controller 50 may then be sent to a relevant party, such as the system manufacturer, for analysis of the system's performance. The data may be used to determine the real conditions from the field, to diagnose malfunctioning systems, and for engineering testing, etc. The data may also be used by trucking fleets for managing the system's use. For example, the data can provide a fleet manager information such as how long a truck was running, how long the air conditioner was running, etc.

FIG. 18 shows another embodiment of the HVAC system according to the present invention. The embodiment in FIG. 18 is similar to the embodiment of FIG. 1; however, FIG. 18 shows how the HVAC system may be divided up into a split system 600 in which there is an exterior subsystem 602 and an interior subsystem 604. The exterior subsystem 602 may comprise components that are located on the exterior area of the vehicle's cab. The interior subsystem 604 may comprise components that are located in the interior area of the vehicle's cab, wherein the interior area includes a driver compartment and a sleeper compartment. The driver compartment is at least partially segregated from the sleeper compartment. FIG. 18 shows an exterior subsystem 602 that comprises a motor 12, a compressor 14, a condenser 16, and a first power source, which are located outside the cab of a large vehicle, such as a truck. In addition, the second power source and the electrical power generation system 44 may also be located on the exterior of the vehicle's cab as is conventional with large vehicles. The exterior subsystem is mounted to a location outside the interior area. For example, the exterior subsystem is mounted to a rear side of the interior area or is mounted underneath the interior area.

The interior subsystem is mounted within the interior area and is to be operably connected with the exterior subsystem. The interior subsystem may be mounted in the sleeper compartment, such as underneath a bed in the sleeper compartment. The interior subsystem 604 may comprise the circulation blower 610, the evaporator 622 and the power management/HVAC component controller 50, the battery management controller 60, the display 310, and the input device 312, which are all located inside the cab of the vehicle. The temperature controlled air may be optionally channeled into ducts 672, which may split into two or more ducts that may lead to different compartments or areas of the interior of the vehicle's cab. In one embodiment, the ducts 672 may be the vehicle's own ducting which is already installed in the vehicle cab. Additionally, the interior subsystem 604 may comprise the vehicle's already existing evaporator 622 and circulation blower 610. In such a situation, the exterior subsystem 602 may be configured to be able to connect to a plurality of different evaporators, such as the vehicle's own evaporator. In addition, the exterior subsystem 602 may be configured to connect to a plurality of evaporators at one time, such as one evaporator for cooling/heating the driving compartment and one evaporator for cooling/heating the sleeping compartment.

In FIG. 18, the refrigerant metering device is located exterior to the vehicle's cab as part of the exterior subsystem 602, which allows the servicing of the metering device to be easier

if it should fail. Alternatively, the refrigerant metering device **20** may be located in the interior of the cab as part of the interior subsystem **604**.

The interior and exterior subsystems may be connected to each other by a liquid phase cooler **1002**, as shown in FIG. **20**. The liquid phase cooler **1002** comprises an outer tube **1004** with two first connectors **1010** and an inner tube **1008** with two second connectors **1006**. The inner tube **1008** is placed within the outer tube **1004**. The tube may be made of any suitable material, such as plastic. Liquid refrigerant can be transferred within the inner tube **1008** or in the outer tube **1004** while gas refrigerant can be transferred in the other tube. The ends **1012** of the outer tube **1004** are sealed so that the fluid running between the inner wall of the outer tube and the outer wall of the inner tube does not leak. If liquid refrigerant is transferred between the inner wall of the outer tube and the outer wall of the inner tube, there is an additional benefit that insulation would not be needed. Furthermore, the boiling of liquid caused by the heating of the liquid by the sun is inhibited; thereby improving the efficiency of the cooling. Also, having one tube inside another would effectively be similar to having a single tube, which would be easier to attach to the back of a truck.

According to one embodiment, the exterior subsystem **602** further includes a quick connect inlet port **1014** and a quick connect outlet port **1016**. The interior subsystem **604** further includes a quick connect inlet port **1018** and a quick connect outlet port **1020**. The inner and outer tubes **1004** and **1008** are first and second quick connect lines, respectively, for operably connecting the exterior subsystem **602** and the interior subsystem **604**. The first quick connect line **1008** connects the quick connect inlet port **1014** of the exterior subsystem **602** and the quick connect outlet port **1020** of the interior subsystem **604**. The second quick connect line **1004** connects the quick connect inlet port **1018** of the interior subsystem **604** and the quick connect outlet port **1016** of the exterior subsystem **602**.

The quick connect inlet port **1014** and the quick connect outlet port **1016** of the exterior subsystem **602** and the quick connect inlet port **1018** and the quick connect outlet port **1020** of the interior subsystem **604** may be low loss quick connect ports. The first and second quick connect lines **1004** and **1008** may be low loss quick connect lines with low loss quick connectors **1006** and **1010**, as seen in FIG. **21(a)**. For low loss quick lines, fluid is retained in the lines because of spring-loaded seals **1024** located in the connectors **1006** and **1010**. When the connectors **1006** and **1010** are attached to their respective mating ports **1014**, **1016**, **1018**, and **1020**, a plunger **1022** within the respective port depresses the spring loaded-seal **1024**, thus permitting fluid to flow through the connect lines. When the connectors and ports are disconnected, the plunger **1022** removes its pressing force from the spring-loaded seal **1024**, thus permitting the seal **1024** to spring back into its sealing position, which allows the fluid within the connect lines to be retained. Therefore, the low loss quick connect ports and the low loss quick connect lines **1004** and **1008** removably connect so that connection and disconnection can take place multiple times with low loss of refrigerant fluid.

Alternatively, the quick connect inlet port **1014** and the quick connect outlet port **1016** of the exterior subsystem **602** and the quick connect inlet port **1018** and the quick connect outlet port **1020** of the interior subsystem **604** may be one-time quick connect ports. The first and second quick connect lines **1004** and **1008** may be one-time quick connect lines with one-time quick connectors **1006** and **1010**, as seen in FIG. **21(b)**. For one-time quick lines, fluid is retained in the

lines because of membranes **1028** located in the connectors **1006** and **1010** providing a seal. When the connectors **1006** and **1010** are attached to their respective mating ports **1014**, **1016**, **1018**, and **1020**, a knife-edge **1026** punctures or ruptures the membrane **1028** within the respective port; thus permitting fluid to flow through the connect lines. The one-time quick connect ports and the low loss quick connect lines **1004** and **1008** will leak if the connectors are removed from their respective ports but provides the advantage of being smaller than the low-loss connectors.

Of course, other connectors and lines may be used for the connectors **1006** and **1010** and the connect lines **1004** and **1008**. For example, the connectors **1006** and **1010** may have flared fittings, sealed fittings, etc. Additionally, various combinations of fitting may be used. For example, both connectors **1010** and **1006** may be low-loss quick connectors, one-time quick connectors, or a combination thereof. According to one embodiment, one of the connectors **1010** and the connectors **1006** are low-loss connectors while the other of the connectors **1010** and the connectors **1006** are one-time quick connectors. According to another embodiment, the connectors **1006** and **1010** that lead to the evaporator **622** (i.e., connecting to the inlet port **1018** and the outlet port **1020** of the interior subsystem **604**) may be one-time quick connectors while the connectors **1006** and **1010** that lead to the condenser **16** (i.e., connecting to the inlet port **1014** and the outlet port **1016** of the exterior subsystem **602**) may be any suitable connector, such as one-time quick connectors, low-loss quick connectors, flared connectors, etc.

The split system **600** has several advantages. First, less interior space is taken up by the system because a substantial portion of the components are located exterior to the vehicle's cab. Additionally, the vehicle's existing ducts may be used so that no additional ducting is needed. Thus, the system may have an easier installation process, improved efficiency, and quieter operation.

The disclosed battery management controller and HVAC system may provide temperature control to a vehicle occupant for extended periods of time when the vehicle's engine is not running. In addition, the system ensures sufficient battery power to start the vehicle even when the HVAC system has been running for a period of time when the engine has been turned off. The battery management and HVAC systems may be used in large trucks, such as 18 wheelers, as well as any other type of vehicle.

During operation, the power management/HVAC component controller **50** processes the user inputs to determine the operational mode of the HVAC system **10**. When either the heating or cooling mode of operation is selected and when the engine is turned on, the vehicle electrical power generation system is used to power the necessary components. For example, the heater and circulation blowers are turned on during the heating mode of operation while the compressor, circulation blowers, and pumps are turned on during the cooling mode of operation.

When the heating mode is operating when the engine is turned off, the power management/HVAC component controller **50** commands a heater (such as the coolant heater **180** in FIG. **2** or the air heaters **270** and **274** in FIG. **1**) and the circulation blowers **210** and **212** to turn on. The power management/HVAC component controller **50** also controls the speed of the circulation blowers **210** and **212** via a pulse width modulated (PWM) PID control loop in order to maintain the temperature of the driving and/or sleeping compartment at the interior set point temperature. With the various disclosed embodiments, the heating of the interior of the cab may be performed without relying on diesel fuel but may be run

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purely by battery power. Thus, the heating may be performed without relying on the vehicle's engine being turned on.

When the cooling mode of operation is used when the engine is turned off, the circulation blowers **210** and **212**, the compressor **14** and/or the pump **176** are turned on. The power management/HVAC component controller **50** modulates the capacity of the compressor **14** and the circulation blowers **210** and **212** to maintain the temperature of the driving and/or sleeping compartment at the interior set point temperature via PID control.

In either the heating or cooling mode when the engine is turned off, if the voltage of the combination of the first and second power sources drops below a predetermined amount, the first and/or second power source is disconnected and the HVAC system is only powered by the remaining power source. Once the voltage of the remaining power source drops below another predetermined level, the battery management controller **60** may be configured to disconnect the remaining power source, thus shutting down the HVAC system **10**.

Upon start up of the vehicle, the alternator or other charging device may be used to charge up the first and second power sources (if they are batteries) so that they are fully charged. In one embodiment of the present invention, the battery management controller **60** may also be used to connect the first power source (such as an auxiliary battery or bank of auxiliary batteries) during the start up of the vehicle in the situation where the second power source (such as the starter battery or bank of batteries) is too weak to start the vehicle, such as in the case where the starter battery is weakened because of very low exterior ambient temperatures.

Furthermore, the HVAC system may be a split system with a substantial portion of the components exterior to the vehicle's cab such that less interior space is taken up by the HVAC system. Also, the vehicle's existing evaporator and/or ducting may be used with the HVAC system for an easier installation process, improved efficiency, and quieter operation.

Operation of the battery management controller will now be described in general with regard to FIG. **19**, which discloses a power generation system. FIG. **19** discloses a power generation system including a pair of power generators **101**, **102**. The generation system also includes main and auxiliary battery systems **131**, **132**. The power generators are connected to an AC power distribution bus **150** and the battery systems are connected to a DC power distribution bus **145**. Although AC and DC busses are shown, the power generation system may include a single DC bus. The power generation system includes AC load(s) **105** and DC load(s) **110**. As mentioned above, the loads may be supplied by a single DC distribution bus and individual inverters provided for each AC load. As shown in FIG. **19**, the power generation system may include an inverter **103** for converting AC to DC power. Alternatively, the system may include a motor/generator set for handling DC/AC or AC/DC power conversion.

As shown in FIG. **19**, the system includes AC power generators but, alternatively, a primary source of DC power may be provided. The power generators **101**, **102** may serve as a charge source for the battery systems **131**, **132**. For example, the power generators may include, for example, a wind turbine generator, a hydro turbine generator, a diesel generator, and a gas turbine generator, etc. The power generation system may include several power transfer units (PTUs) **120** controlled by a battery management or system controller **175**. The PTUs may simply be switches controlling the flow of power along their respective lines. The PTUs may be mounted on one or more printed circuit boards and connected to the necessary wiring, electrical connections, and/or bus bars by

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any suitable means, such as wave soldering. The system may also include a power booster unit **127** (as described above).

The battery management controller **175** may include a control logic circuit and a memory, and may be connected to various system sensors. The battery management controller may be used to regulate the degree of discharge among the power sources so as to conform to the user preferences for battery change and use of various power sources. The memory **67** of the battery management controller may be used to log historical data and use the historical data to modify the operation of the system.

In one exemplary embodiment, the power generator **102** corresponds to a wind turbine generator used for battery charging. The controller **175** is configured to control the system so that the battery could either receive power from the generator **102** or provide power (i.e., motorize) the wind turbine. For example, during periods of no or little wind, the battery (or batteries) could be employed to power the generator **102** to drive the turbine blades and keep the blades spinning at a reasonable rate of speed. Maintaining the turbine rotating, would improve the efficiency of the wind turbine because when the turbine is always ready to make efficient use of each gust of wind to once again charge the batteries. There would be no losses associated with starting or speeding up the turbine.

The system FIG. **19** is an exemplary power generation system that may operate on similar principles to those described above with regard to FIGS. **1-4** and **10-13**. However, FIG. **19** demonstrates that the concepts herein have broad applicability to various power generation systems including multiple power sources including stored energy and rechargeable power sources.

Given the disclosure of the present invention, one versed in the art would appreciate that there may be other embodiments and modifications within the scope and spirit of the invention. Accordingly, all modifications attainable by one versed in the art from the present disclosure within the scope and spirit of the present invention are to be included as further embodiments of the present invention. The scope of the present invention is to be defined as set forth in the following claims.

What is claimed is:

1. An HVAC system to be installed in a vehicle comprising: a battery management controller comprising:
  - at least one connection for electrically coupling a first power source with a first voltage;
  - at least one connection for electrically coupling a second power source with a second voltage; and
  - a first memory storage device configured to record data collected by the battery management controller;
 wherein the battery management controller is configured to run a temperature control system when an engine of the vehicle is turned off and to supply power to the temperature control system when the engine is turned off from a combination of the first and second power sources with a combined voltage, and wherein the second power source is disconnected when the combined voltage drops below a predetermined amount.
2. The HVAC system of claim 1, wherein the battery management controller collects voltage, current, and temperature data, and wherein the data is transmitted to the first memory storage device.
3. The HVAC system of claim 1, wherein the first memory storage device is connected to an input/output device configured to allow the first memory storage device to transmit and receive data to and from a second memory storage device.

- 4. The HVAC system of claim 3, wherein the second memory storage device is a USB memory stick, hard drive, or flash card.
- 5. The HVAC system of claim 1, further comprising an integral timing device connected to the battery management controller, wherein the integral timing device is configured to regulate the HVAC system when the integral timing device reaches a predetermined time value.
- 6. The HVAC system of claim 1, further comprising a user interface connected to the battery management controller and configured to alert a vehicle user about voltage, current, and temperature values.
- 7. The HVAC system of claim 6, wherein the user interface is configured to alert a vehicle user when the combined voltage value reaches a predetermined amount.

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