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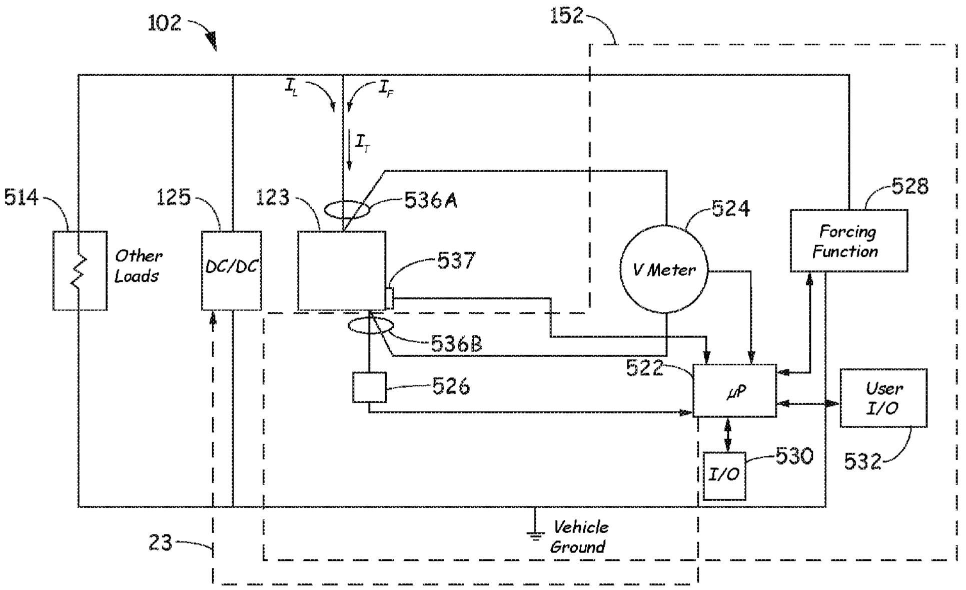


Fig. 9

(57) Abstract: A maintenance device 100 for coupling to electrical circuitry of an electric vehicle 102 for testing the low voltage battery system of the electric vehicle includes electrical connectors 536A/B configured to couple to terminals of a low voltage battery 123 of the low voltage battery system of the vehicle 102 and electrically couple to a DC-to-DC convertor 125 of the vehicle 102 which is used to charge the low voltage battery 123. Measurement circuitry 152 couples to the electrical connectors 536A/B. A controller coupled to the measurement circuitry is configured to measure a parameter of the low voltage battery 123 and a parameter of the DC-to-DC convertor 125 and responsively determine a condition of the low voltage battery 123 and the DC-to-DC convertor 125.

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[Continued on next page]

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# ELECTRIC VEHICLE MAINTENANCE DEVICE FOR LOW VOLTAGE ELECTRICAL SYSTEM

## BACKGROUND

**[0001]** Electric vehicles have large high voltage battery packs used for powering electric motors of the vehicle. Various techniques are known for performing maintenance on these battery packs. However, some electric vehicles also include a low voltage safety performance capacity battery. Problems with the safety performance capacity battery can also cause operation of the electric vehicle to fail.

**[0002]** Various techniques have been pioneered by Dr. Keith S. Champlin and Midtronics, Inc. of Willowbrook, Ill. for testing storage batteries, electric and hybrid vehicles by measuring a dynamic parameter of the battery such as the dynamic conductance of the battery, as well as other techniques. These techniques are described in a number of United States patents, for example, U.S. Patent No. 3,873,911, issued March 25, 1975, to Champlin; U.S. Patent No. 3,909,708, issued September 30, 1975, to Champlin; U.S. Patent No. 4,816,768, issued March 28, 1989, to Champlin; U.S. Patent No. 4,825,170, issued April 25, 1989, to Champlin; U.S. Patent No. 4,881,038, issued November 14, 1989, to Champlin; U.S. Patent No. 4,912,416, issued March 27, 1990, to Champlin; U.S. Patent No. 5,140,269, issued August 18, 1992, to Champlin; U.S. Patent No. 5,343,380, issued August 30, 1994; U.S. Patent No. 5,572,136, issued November 5, 1996; U.S. Patent No. 5,574,355, issued November 12, 1996; U.S. Patent No. 5,583,416, issued December 10, 1996; U.S. Patent No. 5,585,728, issued December 17, 1996; U.S. Patent No. 5,589,757, issued December 31, 1996; U.S. Patent No. 5,592,093, issued January 7, 1997; U.S. Patent No. 5,598,098, issued January 28, 1997; U.S. Patent No. 5,656,920, issued August 12, 1997; 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No. 09/862,783, filed May 21, 2001, entitled METHOD AND APPARATUS FOR TESTING CELLS AND BATTERIES EMBEDDED IN SERIES/PARALLEL SYSTEMS; U.S. Serial No. 09/880,473, filed June 13, 2001; entitled BATTERY TEST MODULE; U.S. Serial No. 10/109,734, filed March 28, 2002, entitled APPARATUS AND METHOD FOR COUNTERACTING SELF DISCHARGE IN A STORAGE BATTERY; U.S. Serial No. 10/263,473, filed October 2, 2002, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT; U.S. Serial No. 09/653,963, filed September 1, 2000, entitled SYSTEM AND METHOD FOR CONTROLLING POWER GENERATION AND STORAGE; U.S. Serial No. 10/174,110, filed June 18, 2002, entitled DAYTIME RUNNING LIGHT CONTROL USING AN INTELLIGENT POWER MANAGEMENT SYSTEM; U.S. Serial No. 10/258,441, filed April 9, 2003, entitled CURRENT MEASURING CIRCUIT SUITED FOR BATTERIES; U.S. Serial No. 10/681,666, filed October 8, 2003, entitled ELECTRONIC BATTERY TESTER WITH PROBE LIGHT; U.S. Serial no. 11/207,419, filed August 19, 2005, entitled SYSTEM FOR AUTOMATICALLY GATHERING BATTERY INFORMATION FOR USE DURING BATTERY TESTER/CHARGING, U.S. Serial No. 11/356,443, filed February 16, 2006, entitled ELECTRONIC BATTERY TESTER WITH NETWORK COMMUNICATION; U.S. Serial No. 12/697,485, filed February 1, 2010, entitled ELECTRONIC BATTERY TESTER; U.S. Serial No. 12/769,911, filed April 29, 2010, entitled STATIONARY BATTERY TESTER; U.S. Serial No. 13/152,711, filed June 3, 2011, entitled BATTERY PACK MAINTENANCE FOR ELECTRIC VEHICLE; U.S. Serial No. 14/039,746, filed September 27, 2013, entitled BATTERY PACK MAINTENANCE FOR ELECTRIC VEHICLE; US Serial No. 14/565,589, filed December 10, 2014, entitled BATTERY TESTER AND BATTERY REGISTRATION TOOL; US Serial No. 15/017,887, filed February 8, 2016, entitled METHOD AND APPARATUS FOR MEASURING A PARAMETER OF A VEHICLE ELECTRICAL SYSTEM; US Serial No. 15/049,483, filed February 22, 2016, entitled BATTERY TESTER FOR ELECTRIC VEHICLE; US Serial No. 15/077,975, filed March 23, 2016, entitled BATTERY MAINTENANCE SYSTEM; US Serial No. 15/149,579, filed May 9, 2016, entitled BATTERY TESTER FOR ELECTRIC VEHICLE; US Serial No. 16/253,526, filed January 22, 2019, entitled HIGH CAPACITY BATTERY BALANCER; US Serial No. 17/364,953, filed July 1, 2021, entitled ELECTRICAL LOAD FOR ELECTRONIC BATTERY TESTER AND ELECTRONIC BATTERY TESTER INCLUDING SUCH ELECTRICAL LOAD; US Serial No. 17/504,897, filed October 19, 2021, entitled HIGH CAPACITY BATTERY BALANCER; US Serial No. 17/750,719, filed May 23, 2022, entitled BATTERY MONITORING SYSTEM; US Serial No. 17/893,412, filed

August 23, 2022, entitled POWER ADAPTER FOR AUTOMOTIVE VEHICLE MAINTENANCE DEVICE; US Serial No. 18/166,702, filed February 9, 2023, entitled BATTERY MAINTENANCE DEVICE WITH HIGH VOLTAGE CONNECTOR; US Serial No. 18/314,266, filed May 9, 2023, entitled ELECTRONIC BATTERY TESTER, US Serial No. 18/324,382, filed May 26, 2023, entitled STACKABLE BATTERY MAINTENANCE SYSTEM, US Serial No. 18/328,827, filed June 5, 2023, entitled ELECTRIC VEHICLE BATTERY STORAGE VESSEL; US Serial No. 18/337,203, filed June 19, 2023, entitled HIGH USE BATTERY PACK MAINTENANCE; US Serial No. 18/609,344, filed March 19, 2024, entitled INTELLIGENT MODULE INTERFACE FOR BATTERY MAINTENANCE DEVICE; US Serial No. 18/616,458, filed March 26, 2024, entitled EV BATTERY CHARGING SOLUTION FOR CONTAINERS; all of which are incorporated herein by reference in their entireties.

## SUMMARY

**[0003]** A maintenance device for coupling to electrical circuitry of an electric vehicle for testing the low voltage battery system of the electric vehicle includes electrical connectors to configured to couple to terminals of a low voltage battery of the low voltage battery system of the vehicle and electrically couple to a DC-to-DC convertor of the vehicle which is used to charge the low voltage battery. Measurement circuity couples to the electrical connectors. A controller coupled to the measurement circuitry is configured to measure a parameter of the low voltage battery and a parameter of the DC-to-DC convertor and responsively determine a condition of the low voltage battery and the DC-to-DC convertor.

**[0004]** This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter. The claimed subject matter is not limited to implementations that solve any or all disadvantages noted in the Background.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0005]** FIG. 1 is a simplified block diagram of a battery maintenance device in accordance with the present invention coupled to an electric vehicle.

**[0006]** FIG. 2 is a more detailed block diagram of the battery maintenance device of FIG. 1.

**[0007]** FIG. 3 is an electrical schematic diagram of a controllable load for use in the battery maintenance device of FIG. 2.

**[0008]** FIG. 4 is a diagram which illustrates one example arrangement of components within the battery maintenance device to promote cooling of such components.

**[0009]** FIG. 5 is a diagram of a plug having an additional load resistance.

**[0010]** FIG. 6 is a perspective view of a housing having resistive loading coils in accordance with one embodiment.

**[0011]** FIG. 7 is a schematic diagram of a controllable resistance load.

**[0012]** FIG. 8 is a graph showing power, discharge current and temperature during battery discharge

**[0013]** FIG. 9 is a simplified electrical diagram of a low voltage junction box configured for testing a low voltage electrical system of an electric vehicle.

## DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

**[0014]** Embodiments of the present disclosure are described more fully hereinafter with reference to the accompanying drawings. Elements that are identified using the same or similar reference characters refer to the same or similar elements. Some elements may not be shown in each of the figures in order to simplify the illustrations.

**[0015]** The various embodiments of the present disclosure may be embodied in many different forms and should not be construed as limited to the specific embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present disclosure to those skilled in the art.

**[0016]** Maintenance of automotive vehicles with internal combustion engines is a well-known art. Procedures are known for servicing the internal combustion engine of the vehicles, the drive train, the battery (which is generally used to start the vehicle and operate the electrical devices within the vehicle), and the fuel storage and distribution system. In contrast, widespread use of electrical vehicles is a relatively new phenomenon and there is an ongoing need for improved procedures for performing maintenance on the batteries of such vehicles. For example, when a traditional vehicle with an internal combustion engine is involved in an accident, it is typical to drain the gasoline or other fuel from the vehicle for safety purposes. In contrast, when an electrical vehicle is involved in an accident, the battery pack of the vehicle may contain a relatively large amount of energy, and may even be in a fully charged state. It is not at all apparent how the battery pack can be discharged as there are many different types of battery pack, as well as various techniques used to access the packs. Further, after an accident, systems of the vehicle may not be functioning properly and may prevent maintenance from being performed on the battery pack whereby the battery pack cannot be discharged using normal procedures. In one aspect, the present invention provides an apparatus and method for safely accessing the battery pack of an electrical vehicle and discharges the battery pack. However, the present invention is not limited to this configuration and may be used generally to perform maintenance on the battery pack of an electric vehicle.

**[0017]** The device of the present invention can be used to "de-power" the battery pack of an electric vehicle or provide other maintenance on the battery pack including charging the battery pack. In general, this activity can be problematic for a number of reasons. First, different types of electric vehicles use different types of battery packs. The configuration, voltages, and connection to such packs vary greatly. Further, the vehicle itself typically includes "intelligence" to control the charging and discharging, as well as monitoring the status of the battery pack. Further still, some battery packs themselves include "intelligence" to control the charging and discharging of the battery pack as well as monitor the status of the battery pack. The device of the present invention is capable of interfacing with a databus of the vehicle and/or a databus of the battery pack in order to control and monitor operation of the battery pack. Again, the connection to these databuses varies greatly between vehicles. Further still, the data format and specific data varies between vehicles. The problem of performing maintenance on a battery pack is exacerbated when a vehicle has been in an accident. The battery pack may be physically difficult to access and it may be difficult to obtain electrical connections to the battery pack and/or vehicle for discharging the battery as well as for communicating over the vehicle or battery pack databus. Depending on the damage which occurs during an accident, the battery pack may be isolated for safety reasons. This isolation presents another challenge in accessing the battery pack. Further, the circuitry of the maintenance device must be capable of operating with the relatively high DC voltages, for example 400 Volts, which are present in electrical vehicle battery packs. These high voltages must be isolated from the logic and control circuitry of the device as well as the operator. Additionally, in one aspect, the device also includes a charger function for use in charging some or all of the cells of a battery pack in order to place the battery pack into service. Further, most electric and hybrid vehicles include a low voltage battery used to operate system of the vehicle. This battery may fail, or the system that changes the battery may fail. In one aspect, the invention is capable of testing this battery and the related charging system.

**[0018]** Electric vehicles typically include "contactors" which are electrically operated relays (switches) used to selectively couple the high voltage from the battery pack to the powerful electric motors used in the drive train of the vehicle. In order to access the battery pack from a location on the vehicle, it is necessary for these contactors to be closed to complete the electrical circuit. However, in an accident, the controlling electronics of the vehicle and/or battery pack will typically disconnect (open) the contactors for safety purposes in order to isolate the battery pack from the vehicle. Thus, in one embodiment, the present invention communicates with the controller of the electrical vehicle or battery pack, or directly with the contactors, to cause the contactors to close and thereby provide access to the high voltage of the battery pack. When communicating with the control system of the vehicle, the device of the present invention can provide information to the vehicle system indicating that it is appropriate for the contactors to close. Thus, failure indications or other errors, including errors associated with a vehicle being in an accident, must be suppressed. Instead, information is provided to the vehicle system by the battery pack maintenance device which indicates that it is appropriate for the contactors to be closed. Further, the device set forth herein can be used to monitor and test parameters of vehicles and batteries which are related to safety.

**[0019]** FIG. 1 is a simplified block diagram showing battery pack maintenance device 100 coupled to an electric vehicle 102. Maintenance device 100 as shown herein can also monitor and test for safety related parameters of vehicles and batteries. The vehicle 102 is illustrated in a simple block diagram and includes a battery pack 104 used to power the vehicle 102 including providing power to motor(s) 106 of the vehicle. The vehicle 102 includes a vehicle controller 108 coupled to a databus 110 of the vehicle. The controller 108 receives information regarding operation of the vehicle through sensors 112 and controls operation of the vehicle through outputs 114. Further, the battery pack 104 is illustrated as including its own optional controller 120 which monitors operation of the battery pack 104 using battery pack sensors 122.

**[0020]** FIG. 1 also illustrates a safety performance capacity battery 123. A safety performance capacity battery is typically a low voltage battery, such as a 12-volt battery, which is used to operate various auxiliary and safety systems within the vehicle 102. The safety performance capacity battery 123 can be used to operate, for example, controller 108, operator I/O 110, along with other devices and equipment within the vehicle 102. The battery 123 is charged, for example, through a DC-to-DC converter 125 which couples to the high voltage output of the battery pack 104. Battery pack 104 typically has a high voltage output which is much too large to directly charge battery 123. The DC-to-DC converter 125 steps down its high voltage to an appropriate voltage, such as 13.5 volts, for charging battery 123.

**[0021]** During operation, the electric vehicle 102 is controlled by the controller 108, for example, based upon input from a driver through operator I/O 109. Operator I/O 109 can comprise, for example, a foot accelerator input, a brake input, an input indicating a position of a steering wheel, information related to a desired gearing ratio for a drive train, outputs related to operation of the vehicle such as speed, charging information, amount of energy which remains in the battery pack 104, diagnostic information, etc. The controller 108 can control operation of the electric motors 106 to propel the vehicle, as well as monitor and control other systems of the vehicle 102. The controller 120 of battery pack 104 can be used to monitor the operation of the battery pack 104. For example, the sensors 122 may include temperature sensors configured to disconnect the batteries of the battery pack if a threshold temperature is exceeded. Other example sensors include current or voltage sensors, which can be used to monitor charge of the battery pack 104. FIG. 1 also illustrates contactor relays 130 of the vehicle 102 which are used to selectively decouple the battery pack 104 from systems of the vehicle 102 as discussed above. For example, the controller 108 can provide a signal to cause the contactors 130 to close thereby connecting the battery pack 104 to electrical systems of the vehicle 102.

**[0022]** Battery pack maintenance device 100 includes a main unit 150 which couples to the vehicle through a low voltage junction box 152 and a high voltage junction box 154. These junction boxes 152, 154 are optional and other techniques may be used for coupling the maintenance device 100 to the vehicle 102. Maintenance device 100 includes a microprocessor 160, I/O circuitry 162 and memory 164 which contains, for example, programming instructions for use by microprocessor 160. The I/O circuitry 162 can be used to both user input, output, remote input, output as well as input and output with vehicle 102. The maintenance device 100 includes a controllable load 170 for use in discharging the battery pack 104. An optional charging source 171 is also provided and can be used in situations in which it is desirable to charge the battery pack 104, for example, to perform maintenance on the battery pack 104. The high voltage junction box 154 is used to provide an electrical connection between terminals of the battery pack 104 and the maintenance device main unit 150. Using this connection, batteries within the battery pack 104 can be discharged using the load 170 or charged using the charging source 171. Similarly, low voltage junction box 152 is used by battery pack maintenance device 100 to couple to low voltage systems of the electric vehicle 102. Such systems include the databus 110 of the vehicle, sensors 112, outputs 114, safety performance capacity battery 123, etc. Through this connection, as discussed above, the maintenance device 100 can gather information regarding the condition of systems within the vehicle 102 including the battery pack 104, and can control operation of systems within the vehicle 102. Similarly, through this connection, the outputs from sensors 112 can be changed or altered whereby altered sensor outputs can be provided to controller 108. This can be used, for example, to cause controller 108 to receive information indicating that the vehicle 102 or battery pack 104 is in a condition which is different than from what the sensors 112 are actually sensing. For example, this connection can be used to cause the contactors 130 to close to thereby provide an electrical connection to the battery pack 104. Further, the low voltage junction box 152 can be used to couple to the controller 120 and/or sensors 122 of the battery pack 104. The junction boxes 152, 154 couple to vehicle 102 through the use of an appropriate connector. The particular connector which is used can be selected based upon the specific type of vehicle 102 and the type of connections which are available to an operator. For example, OBD II connection can be used to couple to the databus 110 of the vehicle. Other plugs or adapters may be used to couple to sensors 112 or outputs 114. A particularly style plug may be available for coupling the high voltage junction box 154 to the battery pack 104. If there are no contactors which are available or if they cannot be accessed or are unresponsive, in one configuration clips or other types of clamp on or selectively connectable contactors can be used to perform the coupling.

**[0023]** FIG. 2 is a simplified block diagram of a battery pack maintenance device 100 in accordance with one example embodiment of the present invention. The device includes microprocessor 160 which operates in accordance with instructions stored in a memory 164. A power supply is used to provide power to the device. The power supply 180 can be coupled to an AC power source, such as a wall outlet or other high-power source, for use in charging the battery pack 104 of the vehicle 102. Additionally, the power supply 180 can be coupled to a DC power source, such as a 12 Volt battery, if the device 100 is only used for discharging of the vehicle battery pack 104. For example, in addition to the battery pack 104, many electric vehicles also include a standard 12 Volt automotive battery 123. This 12 Volt automotive battery can be used to power maintenance device 100. The microprocessor communicates with an operator using an operator input/output 182. Other input/output circuitry 184 is provided for use in physically connecting to a data communication link such as an RS232, USB connection, Ethernet, etc. An optional wireless I/O circuit 186 is also provided for use in communicating in accordance with wireless technologies such as WiFi techniques, Bluetooth®, Zigbee®, etc. Low voltage input/output circuitry 190 is provided for use in communicating with the databus of the vehicle 108, the databus of the battery pack 104, or receiving other inputs or providing outputs to the vehicle 102. Examples include the CAN communication protocol, OBDII, etc. Additionally, contact closures or other voltage inputs or outputs can be applied to the vehicle using the low voltage I/O circuitry 190. FIG. 2 also illustrates an operator shut off switch 192 which can be activated to immediately disconnect the high voltage control 170 from the battery 104 using disconnect switch 194. Other circuit configurations can be used to implement this shut off capability. This configuration allows an operator to perform an emergency shut off or otherwise immediately disconnect the device 100 from the battery if desired.

[0024] The low voltage junction box 152 also provides an optional power output. This power can be used, for example, to power components of the vehicle 102 if the vehicle 102 has lost power. This can be useful, for example, to provide power to the controller 108 of the vehicle 102 such that information may be gathered from the vehicle and various components of the vehicle can be controlled such as the contactors 130. A current sensor, such as an amp clamp, can also be provided.

[0025] In one configuration, the connection between the high voltage control circuitry 170 and the high voltage junction box 154 is through Kelvin type connectors. This can be used to eliminate the voltage drop which occurs when large currents are drawn through wiring thereby provide more accurate voltage measurements. The actual connection between the junction box 154 and the battery pack 104 need not be through a Kelvin connection if the distance between the junction box 154 and the battery pack 104 is sufficiently short for the voltage drop across the connection leads to be negligible. Isolation circuitry such as fuses may be provided in the junction box 154 to prevent the application of a high voltage or current to the maintenance device 100 and thereby protect circuitry in the device. Similarly, the low voltage junction box 152 and/or the low voltage I/O 190 may include isolation circuitry such as optical isolators, inductors to provide inductive coupling, or other techniques. The low voltage junction box 152 may also include an optional user output and/or input 196. For example, this may be a display which can be observed by an operator. An example display includes an LED display, or individual LEDs, which provides an indication to the operator regarding the functioning of the low voltage junction box, the vehicle, or the battery pack. This can be used to visually inform an operator regarding the various functions being performed by the low voltage junction box, voltages detected by the low voltage junction box. A visual output and/or input 198 can be provided on the high voltage junction box 154.

[0026] The appropriate high voltage junction box 154 and low voltage junction box 152 can be selected based upon the particular vehicle 102 or battery pack 104 being inspected. Similarly, the junction boxes 152, 154 can be selected based upon the types of connections which are available in a particular situation. For example, if the vehicle his damaged, it may be impossible to couple to the battery pack 104 through available connectors. Instead, a junction box 154 can be employed which includes connection probes which can be coupled directly to the battery pack 104. Further still, if such a connection is not available or is damaged, connectors can be provided for coupling to individual cells or batteries within the battery pack 104.

[0027] The use of the low voltage and high voltage junction boxes 152, 154 are advantageous for a number of reasons. The junction boxes can be used to provide a standardized connection to the circuitry of the maintenance device 100. From a junction box 152, 154, specialized connectors can be provided for use with different types of vehicles and/or battery packs. Similarly, different types of junction boxes 152, 154 can be utilized for different vehicles and/or battery packs. The junction boxes 152, 154 allow a single set cable connection to extend between the device 100 and a remote location. This provides better cable management, ease of use, and increased accuracy.

[0028] In addition to use as a load for discharging the battery, the high voltage control circuitry may also optionally include a charger for use in charging the battery.

[0029] FIG. 3 is a schematic diagram of controllable load 170. In FIG. 3, a number of isolated gate bipolar transistors (IGBT) 220A, 220B, 220C, and 220D are shown and controlled by a gate connection to microprocessor 160. The IGBTs 220A-D connect to load resistors 222A, 222B, 224A, and 224B. As illustrated in FIG. 3, the four load resistors are 33 OHM resistors. Using the transistors 220A-D, the resistors 222A, B and 224A, B can be coupled in various series-parallel configurations in order to apply different loads to the battery pack 104. In this way, the load applied to the battery pack 104 is controllable by microprocessor 160. In one aspect, the present invention includes isolated gate bipolar transistors (IGBT) to selectively couple loads to the battery pack 104 for discharging the pack. An IGBT is a transistor configured with four semiconducting layers arranged as PNPN. A metal oxide semiconductor is arranged to provide a gate. The configuration provides a transistor which is controlled easily in a manner similar to a field effect transistor but which is also capable of switching large currents like a bipolar transistor.

[0030] When the device 100 is coupled to a vehicle 102 which has been in an accident, the device can perform various tests on the vehicle 102 to determine the condition of the vehicle and the battery. For example, in one aspect, the device 100 detects a leakage between the positive and negative terminals of the battery pack 102 and the ground or chassis of the vehicle 102. For example, a wheat stone bridge circuit 230 can be used between the positive and negative terminals of the battery pack 104 with one of the legs of the bridge connected to ground.

[0031] During discharging of the vehicle battery pack 104, data can be collected from the battery pack. For example, battery packs typically include sensors 122 such as voltage, current and temperature sensors arranged to collect data from various locations within the battery pack. This information can be obtained by the maintenance device 100 via the coupling to the databus

110. During discharge, any abnormal parameters measured by the sensors can be used to control the discharge. For example, if the battery pack 104 is experiencing excessive heating, the discharge rate can be reduced until the battery temperature returns to an acceptable level. If any of the internal temperature sensors of the battery pack are not functioning, an external battery pack temperature sensor can be used to detect the temperature of the battery pack. Similarly, if cells within the pack are experiencing an abnormally high current discharge, the discharge rate can be reduced. Further still, if such data cannot be obtained because the sensors are damages or the databus is damaged or inaccessible, the maintenance device 100 can automatically enter a slow/safe discharge state to ensure that the battery is not damaged.

**[0032]** When placing a battery pack 104 into service, the maintenance device 100 can identify individual cells or batteries within the pack 104 which are more or less charged than other cells. Thus, the individual cells or batteries within a pack can be balanced whereby they all have substantially the same charge capacity and/or state of charge as the other cells or batteries within the pack.

**[0033]** In another aspect of the present invention, the maintenance device 100 is capable of providing a “jump start” to a hybrid electric vehicle 102. For example, if the internal combustion engine of a hybrid electric vehicle is started using power directly from the battery pack and if the charge of the battery pack 104 is too low, there is insufficient energy available to start the engine. The maintenance device 100 of the present invention can be used to provide sufficient power to a starter motor of the internal combustion engine for starting the engine. Once the internal combustion engine is running, the engine itself is used to charge the battery pack 104.

**[0034]** In FIG. 3, a voltage sensor 232 is connected across the wheat stone bridge 230. Further, the bridge is optionally connected to electrical ground through switch 234. Any voltage detected by voltage sensor 232 across the bridge 230 is an indication that there is a current leak between the positive and/or negative terminals of the battery pack 104 and the electrical ground or chassis of the vehicle 102. The voltage sensor 232 can provide an output to microprocessor 130 and used to alert an operator to a potentially dangerous situation and indicate that the battery pack 104 must be disconnected from the vehicle 102 before further maintenance is performed.

**[0035]** FIG. 3 also illustrates a relay 226 which is used to isolate the load resistances 222/224 from the battery pack until a discharge is commanded by the microprocessor 160. The voltage across the battery pack 104 can be measured using a voltage sensor 242 connected in series with a resistance 240. The output from sensor 242 is provided to microprocessor 160 for use in performing maintenance in the battery pack 104.

**[0036]** During operation, the components of the device 100 may experience a great deal of heating. An air flow cooling system can be used to dissipate the heat. FIG. 4 shows one such configuration. As illustrated in FIG. 4, the air flow moves from the low power electronics 300, passed the high-power electronics 302 and over the load resistors 222A, B and 224A, B. The air flow then leaves the housing of the device 100. In FIG. 4, the air flow is controlled by fans 304. The fans 304 can be controlled using microprocessor 160 whereby their speed can be adjusted as needed based upon measurements from temperature sensors 306 which can be placed at various locations within the housing of device 100. In this configuration, hot air generated by the load resistance is immediately blown out of the housing rather than past any components.

**[0037]** Some electrical vehicles include what is referred to as a "pre-charge contactor." The pre-charge contactor can be used to charge capacitances of the vehicle at a slow and controlled rate prior to switching in the main contactor 130 shown in FIG. 1. This prevents excessive current discharge from the battery pack when the main contactor is activated and the pack is directly coupled to the loads of the vehicle including the traction module of the vehicle which is used to control electric motors of the vehicle.

**[0038]** In another aspect, some or all of the information obtained during testing and discharge of a battery pack 104 is retrieved and stored, for example in the memory 164 shown in FIG. 1, for subsequent access. This information can be offloaded to another device, for example a USB drive or the like, or transmitted over a network connection. This can be particularly useful to examine information retrieved after a vehicle has experienced an accident. The information can be information which is downloaded from the controller 108 of the vehicle 102 and may also be information related to how the vehicle battery pack 104 was discharged and removed of service.

**[0039]** In another aspect, more than one maintenance device 100 can be coupled to a battery pack 104 and the multiple devices can be configured to work in tandem. More specifically, the devices 100 can be coupled using the input/output circuitry 184 shown in FIG. 2 whereby one of the devices 100 operates as a master and one or more other devices 100 operate as slaves under the control of the master device. This arrangement can be used to increase the rate at which a battery pack 104 is discharged. In such a configuration, a bridgeable power supply may also be employed.

**[0040]** FIG. 5 is a simplified diagram showing a removable plug 350 which can be selectively coupled to battery pack maintenance device 100. Removable plug 350 includes a 5 OHM resistor 352 configured to connect in parallel through connectors 354 and 356. Removable plug 350 includes a magnet 360 configured to actuate a reed switch 362. Reed switch 362 connects to microprocessor 160 whereby microprocessor 160 can sense the presence of the plug 350. When plug 350 is coupled to device 100, the resistance of one or more of the 33 OHM resistors 222A,B and 224 A,B can be changed because the resistor is in series with the 5 OHM resistor yielding a resistance of about 4.3 OHMs. However, any configuration desired can be provided. This allows the device 100 to apply a smaller resistance to the battery pack 104 thereby increasing the discharge rate if desired. For example, a particular battery pack may be of a sufficiently low voltage to allow for an increased current draw to thereby increase the rate at which the battery pack 104 is discharged. Using reed switch 362, the microprocessor 160 is able to detect the presence of the plug 350 whereby calculations which rely on the value of applied load resistance can be compensated appropriately. Although only a single resistor 352 is shown, the plug 350 may include any number of resistors to be placed in parallel with load resistances in the device 100. Preferably plug 350 includes a cooling mechanism to reduce the heating of resistor 352. For example, the plug 350 may include metal or other heat conducting fins or the like. A fan may also be employed. The fan may be the same cooling fan used in device 100 or, plug 350 may optionally include its own fan. In another embodiment, the alternative resistance values are located within the main unit, and are switched into circuit using the removable plug.

**[0041]** FIG. 6 is a perspective view of another example embodiment of a controllable load 170 illustrated in a housing 402. In the configuration of FIG. 6, resistive elements are provided using a number of resistive coils 400. In one example embodiment, these resistive coils can be the type of coils used in consumer applications such as electric clothing dryers. For example, one such coil is rated at approximately 5.3 KW at 240 volts. Note that if the rated voltage is exceeded, the coil will melt and become an open circuit. Further, it is also preferable that the coils 400 have resistances which are similar. The coils 400 are carried on supports 404 preferably made of an electric insulator capable of handling high temperatures. To assist in heat dissipation, an air flow can be provided across the coils 400 as shown in FIG. 4.

**[0042]** FIG. 7 is a simplified schematic diagram of another example embodiment of controllable load 100. In the configuration of FIG. 7, the four coils 400 illustrated in FIG. 6 are electrically connected in a series/parallel configuration. In this configuration, switches K1, K2, K3 and K4 are provided for controlling the resistance provided by controllable load 100. These switches can be any type of switch including relays or transistor switches. In one configuration, the switches are manual switches. Switches K1 and K2 control two parallel legs of the circuit while switches K3 and K4 control the amount of resistance in series in each leg. In this configuration, a maximum discharge capability of 20 KW is provided if both switches K1 and K2 are closed and switches K3 and K4 are open. The B+ and B- connections are used for coupling to the storage battery and fusible links 406 are provided for safety. In one example configuration, if the voltage across terminals B+ and B- drops below 240 volts DC, switch K3 and/or switch K4 can then be closed to reduce the resistance applied to battery 104 and optimize the loading of the battery. FIG. 8 is a graph showing the loading performance of such an arrangement. As illustrated in FIG. 8, the step change occurs when the resistive load provided by controllable load 100 is decreased, for example, by activating switch K2.

**[0043]** As mentioned above, the fans illustrated in FIG. 4 can be used to provide an air flow across the coils 400. In one configuration, all of the fans control circuits and relays may be operated by 12-volt DC and can be powered, for example, by an auxiliary battery or a "cigarette lighter" output from a vehicle such as a tow truck. A double insulation technique can be used proximate the load coils such that any electrical fault, for example a heater coil failure, cannot be conducted to a location outside of the housing 402. Optional temperature safety sensors 306 shown in FIG. 4 can be used. The temperature sensors 306 can be provided on both the inlet and the outlet of each heater coil and can be used to detect fan failure or blocked air flow. This configuration can also be used to detect the amount that the air is heated by the coil. In another example configuration, fusible links 404 may provide hard wired temperature cutout switches to prevent overheating. In such a configuration, when a temperature threshold is reached, the switch will open. Data obtained during discharge can be logged to a memory such as memory 164 such as a local flash drive or other local storage device. In another configuration, the logged data is sent to a remote location such as cloud storage for analysis. Such records can be of significance for warranty or insurance purposes.

**[0044]** In one configuration, the voltage sensor 232 is used to detect leakage currents in the battery undergoing discharge. The device can also monitor battery cell voltages and temperatures to ensure that unsafe conditions are not being created during discharge.

**[0045]** The input/output circuitry 190 can be used to connect to a databus of the vehicle, for example, through an OBDII connection in order to collect information such as VIN, software and hardware version numbers, etc. The device can communicate with the battery ECU (Electronic Control Unit) using any appropriate protocol including CAN, LIN, or others, in order to obtain specific battery information and discharge protocols. The device can be connected as a slave unit to another piece of shop equipment either using a hardwired connection or a wireless connection such as Bluetooth or Wi-Fi. Reverse polarity protection as well as overvoltage protection can be provided. Other safety techniques for electrical potential, temperature and axis points can be fully interlocked to prevent operation of the unit. In one configuration, the input/output 184 can include a barcode scanner which can then be used to capture specific information such as battery type or serial number as well as vehicle identification number, etc. In another example configuration, input/output circuitry 184 can include a remote temperature sensor that can be electrically coupled to the discharger to report battery temperature. This is useful when internal battery temperature sensors are damaged or inoperative. The devices are scalable such that multiple controllable loads 100 can be connected in parallel. Relay contacts can also be provided and available externally to control various circuits on the battery pack undergoing discharge. Additional voltage sensing connections such as those provided by junction box 152 can be used to monitor various circuits on the battery pack.

**[0046]** Another example configuration includes a high voltage DC-to-DC converter such as power supply 180 shown in FIG. 2. In such a configuration, the high voltage output from the battery pack can be converted to a lower DC voltage for use in powering the device.

**[0047]** As discussed above, in some configurations the present invention can be arranged to measure a dynamic parameter of the battery pack. In such a configuration, a forcing function is applied to the battery pack and a dynamic parameter such as dynamic conductance, resistance, admittance, etc. can be determined based upon a change in the voltage across the battery pack and the current flowing through the battery pack. The forcing function can be any type of function which has a time varying aspect including an AC signal or a transient signal.

**[0048]** In one aspect, the maintenance device can be configured to “balance” individual cells within the battery pack. The balancing can be performed by selected cells or individual batteries within the pack which have similar storage capacity and state of charge. The charging feature of the device can be used to increase the charge of a cell or battery to that of other cells or batteries. Similarly, the maintenance device can be used to discharge individual cells or batteries to a level similar to that of other cells or batteries within the pack.

**[0049]** In another aspect, the device of FIG. 1 includes an ambient temperature sensor. The microprocessor can use information from the ambient temperature sensor in determining how the battery pack should be discharged. For example, if the ambient temperature is high, the discharge rate can be reduced.

**[0050]** During discharge of the battery pack, the discharge profile can be monitored to ensure proper operation. For example, if the voltage of the battery suddenly drops, this can be an indication that a component within the battery has failed or a short circuit has occurred.

**[0051]** Different types of junction boxes and connection cables can be used based upon the particular type of vehicle and battery pack under maintenance. The microprocessor can provide information to the operator prompting the operator to use the appropriate junction box or cable. This can be based upon the operator inputting the vehicle identification number (VIN) to the microprocessor, or other identifying information including an identification number associated with the battery pack. During discharging of the battery pack, the microprocessor can also provide information to the operator which indicates the time remaining to complete the discharge. The microprocessor 160 can also detect if the correct junction box and cable have been coupled to the device and to the battery pack for the particular battery pack and vehicle under maintenance. Information can be provided to the operator if the wrong cabling or junction box has been employed.

**[0052]** The device of the present invention can be used with battery packs which have been removed from a vehicle as well as individual batteries, or groups of batteries, within a pack. For example, a battery pack typically includes a battery connector assembly which is used by the vehicle 102 to couple to the battery pack 104. However, when the battery pack 104 is removed from the vehicle 102, the device 100 can directly couple to this battery connector assembly and thereby charge or discharge the battery pack, perform tests on the battery pack, interact with devices on the battery pack including sensors, controllers, etc. As discussed above, the device 100 can include multiple connectors for use in connecting the low voltage junction box 152 and/or the high voltage junction box 154 to the vehicle 102 and/or battery pack 104. This allows the device 100 to easily be modified to interact with different types of batteries or vehicles by simply selecting the appropriate connector. In one configuration, the connectors include some type of identifier which can be read by the device 100 whereby the microprocessor 160 and device 100 can receive information to thereby identify the type of connector in use. This allows the microprocessor 100 to know what types of information or tests may be available through the various connectors. In another example, the operator uses operator I/O 182 shown in FIG. 2 to input information to the microprocessor 160 related to the type of connector(s) being used. In another example embodiment, the microprocessor 160 may receive information which identifies the type of vehicle or battery on which maintenance is being performed. This information can be input by an operator using the operator I/O 182, or through some other means such as by communicating with the databus of the vehicle, scanning a barcode or other type of input, etc. Based upon this information, the microprocessor can provide an output to the operator using operator I/O 182 which informs the operator which type of interconnect cable should be used to couple the low voltage junction box 152 and/or the high voltage junction box 154 to the vehicle and/or battery pack.

**[0053]** The operator I/O 182 may include a display along with a keypad input or touchscreen. The input may take various formats, for example, a menu driven format in which an operator moves through a series of menus selecting various options and configurations. Similarly, the operator I/O 182 can be used by the microprocessor 160 to step the operator through a maintenance procedure. In one configuration, the memory 164 is configured to receive a user identification which identifies the operator using the equipment. This can be input, for example, through operator I/O 182 and allows information related to the maintenance being performed to be associated with information which identifies a particular operator. Additional information that can be associated with the maintenance data include tests performed on the vehicle and/or battery, logging information, steps performed in accordance with the maintenance, date and time information, geographical location information, environmental information including temperature, test conditions, etc., along with any other desired information. This information can be stored in memory 164 for concurrent or subsequent transmission to another device or location for further analysis. Memory 164 can also store program instructions, battery parameters, vehicle parameters, testing or maintenance information or procedures, as well as other information. These programming instructions can be updated, for example, using I/O 184 or 186, through an USB flash drive, SD card or other memory device, or through some other means as desired. This allows the device 100 to be modified, for example, if new types of vehicles or battery pack configurations are released, if new testing or maintenance procedures are desired, etc.

**[0054]** Additionally, the present invention provides a method and apparatus for conducting a comprehensive test of an Electric Vehicle (EV) low-voltage (LV) electrical system, principally comprised of a LV battery 123 (not limited to, but often ranging from 12V-16V) and a DC-DC converter 125 (DC-DC converter charges LV battery). The test involves the evaluation of the LV Battery Safety Power Capacity Diagnostics and the functionality of the DC-DC converter 124. The combined test includes individual assessments of the 12V battery, the application of loads to the battery 123, and verification of the output current of the DC-DC converter 125 increases sufficiently to charge the 12V battery 123. Various measurement techniques, such as the utilization of a diagnostic charging device load coils (such as load resistors 222) and an Amp Clamp, can be used to determine the charging current from the DC-DC converter.

Additionally, in one alternative, the charging current may be measured directly at the battery clamps when the voltage increases under load, rendering the Amp Clamp unnecessary in certain scenarios.

**[0055]** In this configuration, FIG. 9 is a simplified block diagram showing an automotive vehicle 102 which couples to a battery monitor in accordance with one embodiment of the present invention. Vehicle 102 includes vehicle loads 514 which are shown schematically as an electrical resistance. Battery 123 is coupled to the vehicle load 514 and to DC-to-DC converter 125. DC-to-DC converter 125 couples to battery pack 104 of the vehicle 102 and is used to charge battery 123 and provide power to loads 514 during operation.

**[0056]** In general, automotive vehicles include electrical systems which can be powered by battery pack 104 using DC-to-DC converter 125. However, if the pack 104 fails, the safety performance battery 123 in the vehicle is used to power the system. Thus, the DC-to-DC converter 125 in the vehicle serves two purposes. The converter 125 is used to supply power to the vehicle loads, such as lights, computers, radios, defrosters and other electrical accessories. Further, the converter 125 is used to recharge the battery such that the battery and such that the battery may power the electrical accessories if the battery pack 104 fails.

**[0057]**

**[0058]** In the embodiment illustrated in FIG. 9, the battery monitor is implemented in LV junction box 152 and includes a microprocessor 522 coupled to a voltage sensor 524, a current sensor 526 and a forcing function 528. Microprocessor 522 may also include one or more inputs and outputs illustrated as I/O 530 adapted to couple to an external databus and/or to an internal databus associated with the vehicle 102. Further, a user input/output (I/O) 532 is provided for providing interaction with a technician. In one embodiment, microprocessor 522 is coupled to DC-to-DC converter 125 through the vehicle databus to provide a control output 523 to converter 125 in response to inputs, alone or in various functional combinations, from current sensor 526, voltage sensor 524 and forcing function 528 .

**[0059]** FIG. 9 also illustrates a Kelvin connection formed by connections 536A and 536B to battery 123. With such a Kelvin connection, two couplings are provided to the positive and negative terminals of battery 123. This allows one of the electrical connections on each side of the battery to carry large amounts of current while the other pair of connections can be used to obtain accurate voltage readings. Because substantially no current is flowing through the voltage sensor 524, there will be little voltage drop through the electrical connection between sensor 524 and battery 123 thereby providing more accurate voltage measurements. In various embodiments, the forcing function 528 can be located physically proximate battery 123 or be connected directly to battery 123. In other embodiments, the forcing function 528 is located anywhere within the electrical system of vehicle 102. Current sensor 526 and may be capable of monitoring battery condition while the vehicle 102 is operated, loads 514 are turned on and/or DC-to-DC converter 125 is providing a charge signal output to charge battery 123. In one particular embodiment, the combination of the Kelvin connection formed by connections 536A and 536B, along with a current sensor 526 connected is provided and allows monitoring of the condition of battery 123. The use of a current sensor 526 is used to provide a monitor of the total current IT flowing through battery 123.

**[0060]** In operation, low voltage junction box 152 is capable of measuring a dynamic parameter of battery 123. As used herein, a dynamic parameter includes any parameter of battery 123 which is measured as a function of a signal having an AC or transient component applied, for example, by forcing function 528. Examples of dynamic parameters include dynamic resistance, conductance, admittance, impedance or their combinations. In various aspects of the invention, this measurement can be correlated, either alone or in combination with other measurements or inputs received by microprocessor 522, to the determine the condition or status of battery 123. This correlation can be through testing of various batteries and may be through the use of a lookup table or a functional relationship such as a characterization curve. The relationship can also be adjusted based upon battery construction, type, size or other parameters of battery 123 including temperature measured by temperature sensor 537. Examples of various testing techniques are described in the following references which are incorporated herein by reference U.S. Patent No. 3,873,911, issued March 25, 1975, to Champlin; U.S. Patent No. 3,909,708, issued September 30, 1975, to Champlin; U.S. Patent No. 4,816,768, issued March 28, 1989, to Champlin; U.S. Patent No. 4,825,170, issued April 25, 1989, to Champlin; U.S. Patent No. 4,881,038, issued November 14, 1989, to Champlin; U.S. Patent No. 4,912,416, issued March 27, 1990, to Champlin; U.S. Patent No. 5,140,269, issued August 18, 1992, to Champlin; U.S. Patent No. 5,343,380, issued August 30, 1994; U.S. Patent No. 5,572,136, issued November 5, 1996; U.S. Patent No. 5,574,355, issued November 12, 1996; U.S. Patent No. 5,583,416, issued December 10, 1996; U.S. Patent No. 5,585,728, issued December 17, 1996; U.S. Patent No. 5,589,757, issued December 31, 1996; U.S. Patent No. 5,592,093, issued January 7, 1997; U.S. Patent No. 5,598,098, issued January 28, 1997; U.S. Patent No. 5,656,920, issued August 12, 1997; U.S. Patent No. 5,757,192, issued May 26, 1998; U.S. Patent No. 5,821,756, issued October 13, 1998; U.S. Patent No. 5,831,435, issued November 3, 1998; U.S. Patent No. 5,871,858, issued February 16, 1999; U.S. Patent No. 5,914,605, issued June 22, 1999; U.S. Patent No. 5,945,829, issued August 31, 1999; U.S.

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**[0061]** In the specific embodiment illustrated in FIG. 9, the forcing function 528 is a function which applies a signal having an AC (or having a time varying or transient component) to battery 123. The forcing function can be through the application of a load which provides a desired forcing function in which current is drawn from battery 123, or can be through active circuitry in which a current is injected into battery 123. This results in a current labeled IF in FIG. 9. The total current, IT through battery 123 is due to both the forcing function current IF and the current flowing through loads 514, IL. Current sensor 526 is positioned to sense the total current $I_L$. One example battery dynamic parameter, the dynamic conductance (or reciprocally the battery resistance) can be calculated as:

$$\Delta G = V = \Delta I_T / \Delta V \qquad \text{EQ. 1}$$

where $\Delta V$ is the change in voltage measured across the battery 123 by voltage sensor 524 and $\Delta I_T$ is the change in total current measured flowing through battery 123 using current sensor 526. Note that Equation 1 uses current and voltage differences. The forcing function 528 is provided in order to ensure that the current through battery 18 changes with time. However, in one embodiment, changes in IL due to loads 514 or the output from DC-to-DC converter 125 can be used alone such that $\Delta IT = \Delta IL$ and the forcing function 528 is not required. In one aspect, the forcing function 528 is provided by normal or specially controlled operation of loads 514.

**[0062]** Furthermore, microprocessor 22 can detect a failure of the voltage regulator and DC-to-DC converter 123 if the voltage output exceeds or drops below predetermined threshold levels. This information can be provided to an operator through user interface 532, for example, a "service soon" indication.

**[0063]** A temperature sensor 537 is provided which can be coupled directly to one of the terminals of the battery 123 for measuring battery temperature, or measure battery temperature using an infrared sensor. The temperature sensor 537 can be used in determining the condition of the battery 123, as battery condition is a function of temperature. Any type of temperature sensor can be used, for example, a thermistor, thermocouple, RTD, semiconductor or other temperature sensor.

**[0064]** In one embodiment, current sensor 526 comprises a resistance shunt of 250 μohms and current through the shunt is determined by measuring the voltage drop across the shunt. However, other types of current measurement techniques can also be used, such as Hall Effect sensors or through an inductance probe. The change of voltage across the battery and the resultant change in current through the battery is sampled using, for example, one or more analog to digital converters. In one configuration, the current sensor 526 is arranged to only measure the current IF applied by the forcing function 528. This information can be correlated to determine the total capacity, such as the total Cold Cranking Amp (CCA) capacity of the battery.

**[0065]** In implementing these diagnostics, components of the high voltage junction box 154 can be coupled to the low voltage battery 123 for additional functionality. In one example configuration, a combined test is implemented for both 12V battery diagnostics along with a DC-DC converter functionality test. This method involves performing a comprehensive assessment of the electrical vehicle low voltage system, combining the evaluation of the low voltage battery 123 diagnostics and the functionality of the DC-DC converter 125.

**[0066]** First, the low voltage battery 123 is tested alone. The first step of the combined test is to evaluate the LV battery in isolation, measuring its Reserve State of Charge, Reserve State of Health, and Working Amp Hours by applying a forcing function as discussed above. If the condition of battery 123 is outside of specified limits, the operator can be informed that the battery needs replacement.

**[0067]** To test the resilience and functionality of the LV battery 123, various loads can be applied. These loads simulate real-world usage scenarios and assess the battery's capacity to sustain the required power. The loads can be applied using internal vehicle loads 514, through forcing function 528, or using the loads available in the high voltage junction box 154. The change in battery voltage during and/or after application of the load can be monitored to determine if it is within specification and the operator alerted as needed.

**[0068]** In another aspect, operation of the DC-to-DC converter 125 is verified. The DC-to-DC converter can 125 can be activated by low voltage junction box 152 communication with vehicle 102 over the vehicle databus. The amount of charge current flowing into battery 123 can be monitored using current sensor 526 to ensure that it is sufficiently large to charge the battery.

**[0069]** In another test, a load is applied to DC-to-DC converter 125 using, for example, forcing function 528 or resistors 222,224to replicate the behavior of a battery 123. This load effectively simulates a battery, enabling accurate evaluation of the converter 125 charging performance.

**[0070]** In another test, the amp clamp current sensor 526 is used as an alternative method to determine the charging current from the DC-to-DC converter 125. This measurement technique provides an accurate assessment of the output current of the converter 125.

**[0071]** In another configuration, the charging current is measured directly at the battery clamps. For example, an increase in voltage when a load is applied can be used to infer the charging current. This technique can be used to eliminate the need for an amp clamp current sensor in some cases.

**[0072]** This comprehensive test method ensures the proper functioning and reliability of the EV LV system by evaluating the LV Battery SPC diagnostics and confirming the DC-to-DC converter's ability to charge the LV battery effectively. The measurement techniques, including the use of diagnostic charger load coils and the amp clamp, offer accurate and efficient means of assessing the system's performance during the test.

**[0073]** EV System Test:

**[0074]**

**[0075]** The combined testing procedure is as follows:

a. Test 12V battery 123 alone.
b. Apply loads to 12V battery 123.

c. Confirm DC-to-DC converter 125 output current increases to charge 12V Battery 123.
   i. Apply a load, which acts as a battery, for use in DC-to-DC converter 123 charging-test.
   ii. Use amp clamp current sensor 526 to determine charging current from the DC-to-DC converter 125.
   iii. Measure the charging current at battery clamps as voltage increases under load.
d. Provide an output to an operator based on tests a-c.

**[0076]**

**[0077]** Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. Although specific embodiments describe increasing the load or current, it should be understood that the change in applied load or current drawn can be either increasing or decreasing.

WHAT IS CLAIMED IS:

1. A maintenance device for coupling to electrical circuitry of an electric vehicle for testing the low voltage battery system of the electric vehicle, comprising:

electrical connectors to configured to couple to terminals of a low voltage battery of the low voltage electrical system of the vehicle and electrically couple to a DC-to-DC convertor of the vehicle which is used to charge the battery;

measurement circuity coupled to the electrical connectors; and

a controller coupled to the measurement circuitry configured to measure a parameter of the battery and a parameter of the DC-to-DC convertor and responsively determine a condition of the battery and the DC-to-DC convertor.

2. The maintenance device of claim 1 including an electrical load configured to couple to the battery through the electrical connectors.

3. The maintenance device of claim 2 wherein the battery parameter is determined based upon application of the electrical load.

4. The maintenance device of claim 2 wherein the DC-to-DC convertor parameter is determined based upon application of the electrical load.

5. The maintenance device of claim 2 wherein the DC-to-DC convertor parameter and the battery parameter are determined based upon application of the electrical load.

6. The maintenance device of claim 2 wherein the resistance of the load is adjustable.

7. The maintenance device of claim 1 wherein the electrical connectors are Kelvin connectors.

8. The maintenance device of claim 1 wherein the controller is configured to control operation of the DC-to-DC convertor.

9. The maintenance device of claim 1 including a low voltage junction box configured to couple to low voltage systems of the vehicle.

10. The maintenance device of claim 1 including a connection to a databus of the vehicle and wherein the controller is configured to communicate with the databus.

11. The maintenance device of claim 10 wherein the controller applies vehicle loads to the battery by communicating through the databus.

12. The maintenance device of claim 1 including a current sensor configured to measure a flow of electrical current into the battery.

13. The maintenance device of claim 11 wherein the current sensor comprises a voltage sensor configured to sense a voltage related to a charging current.

14. A method of performing maintenance on electrical circuitry of an electric vehicle for testing a low voltage system of the electric vehicle, comprising:

connecting electrical connectors to terminals of a low voltage battery of the low voltage electrical system of the electric vehicle and electrically coupling to a DC-to-DC converter of the electric vehicle which is used to charge the low voltage battery;

measuring a parameter of the low voltage battery of the electric vehicle to the electrical connectors;

measuring a parameter of the DC-to-DC through the electrical connectors; and

determining condition of the low voltage battery based upon the measured parameter of the battery and condition of the DC-to-DC converter based upon the measured parameter of the DC-to-DC converter.

15. The method of claim 14 including coupling an electrical load configured to couple to the battery through the electrical connectors.

16. The method of claim 15 wherein the battery parameter is determined based upon application of the electrical load.

17. The method of claim 15 wherein the DC-to-DC convertor parameter is determined based upon application of the electrical load.

18. The method of claim 15 wherein the DC-to-DC convertor parameter and the battery parameter are determined based upon application of the electrical load.

19. The method of claim 15 including adjusting a resistance of the load is adjustable.

20. The method of claim 14 wherein the electrical connectors are Kelvin connectors.

21. The method of claim 14 wherein including controlling operation of the DC-to-DC convertor.

22. The method of claim 14 including providing a low voltage junction box configured to couple to low voltage systems of the vehicle.

23. The method of claim 14 including connecting to a databus of the vehicle and communicating with the databus.

24. The method of claim 23 wherein including applying vehicle loads to the battery by communicating through thc databus.

25. The method of claim 1 measuring a flow of electrical current into the battery.

26. The method of claim 14 wherein measuring the flow of current into the battery comprises sensing a voltage related to a charging current.

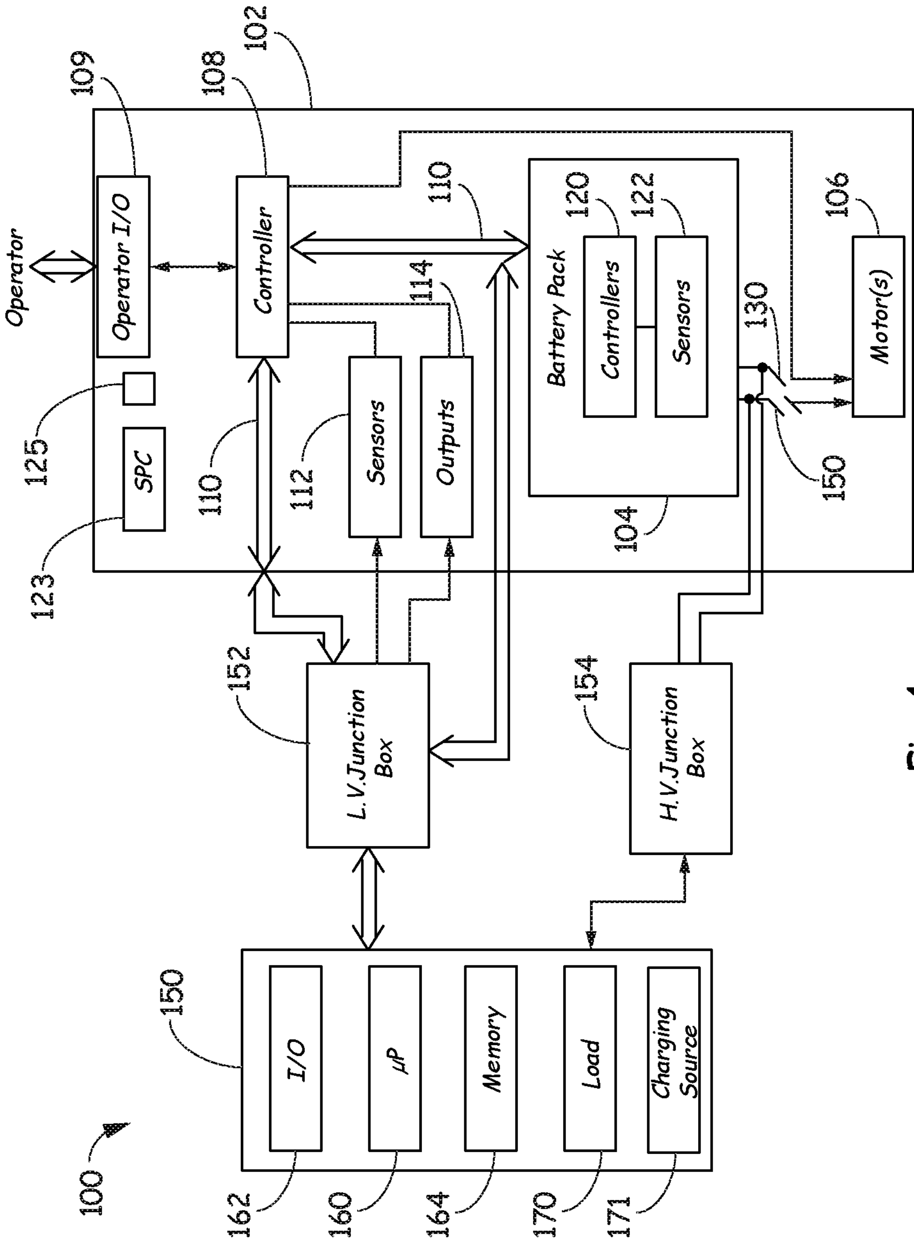

Operator
Operator I/O
Controller
Sensors
Outputs
Battery Pack
Controllers
Sensors
Motor(s)
SPC
L.V.Junction Box
H.V.Junction Box
I/O
μP
Memory
Load
Charging Source
100
102
104
106
108
109
110
112
114
120
122
123
125
130
150
152
154
160
162
164
170
171

Fig. 1

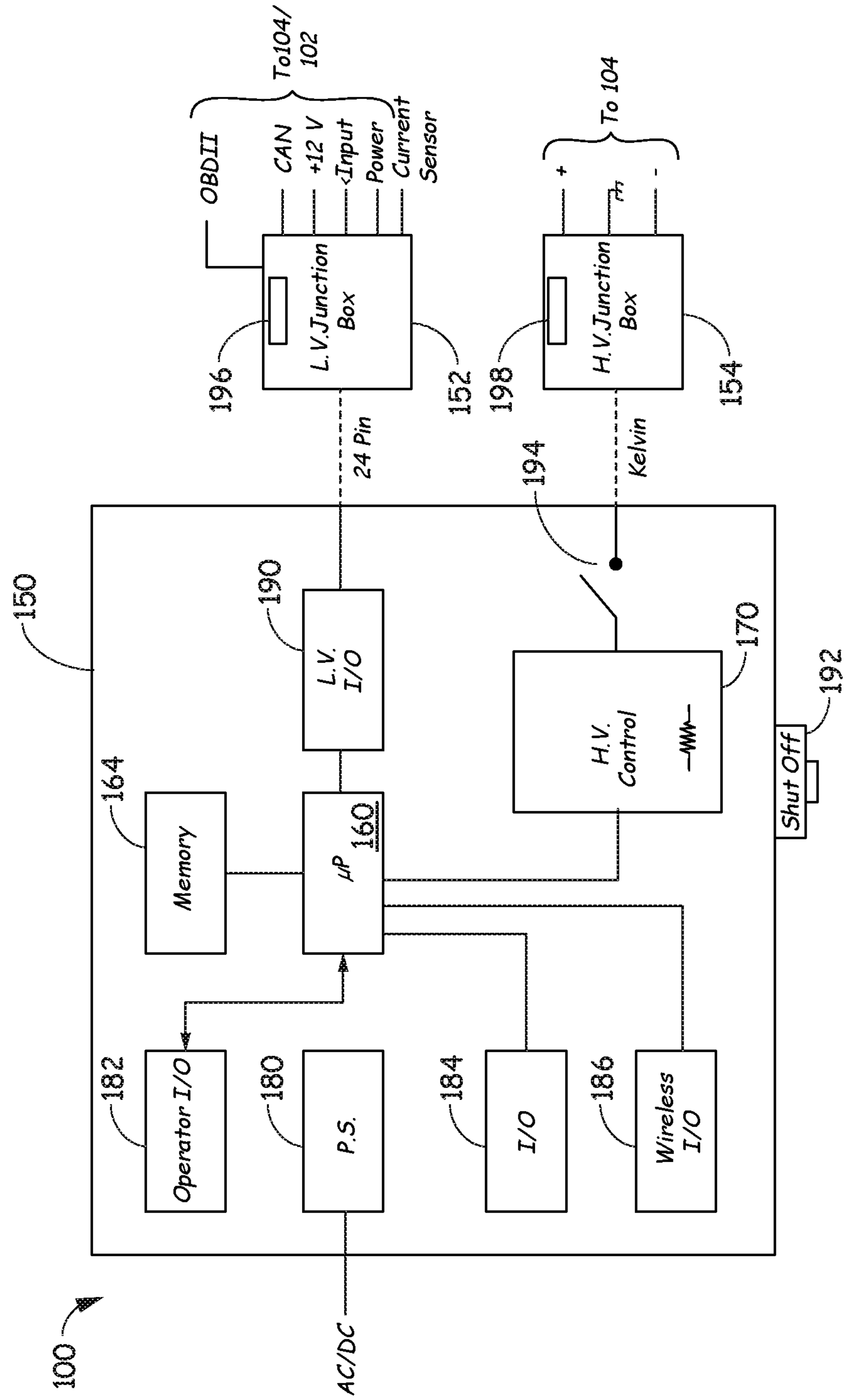

To104/
102
OBDII
CAN
+12 V
Input
Power
Current
Sensor
L.V.Junction
Box
196
152
24 Pin
To 104
+
-
H.V.Junction
Box
198
154
Kelvin
194
150
190
L.V.
I/O
170
H.V.
Control
192
Shut Off
164
Memory
µP
160
182
Operator I/O
180
P.S.
184
I/O
186
Wireless
I/O
100
AC/DC

Fig. 2

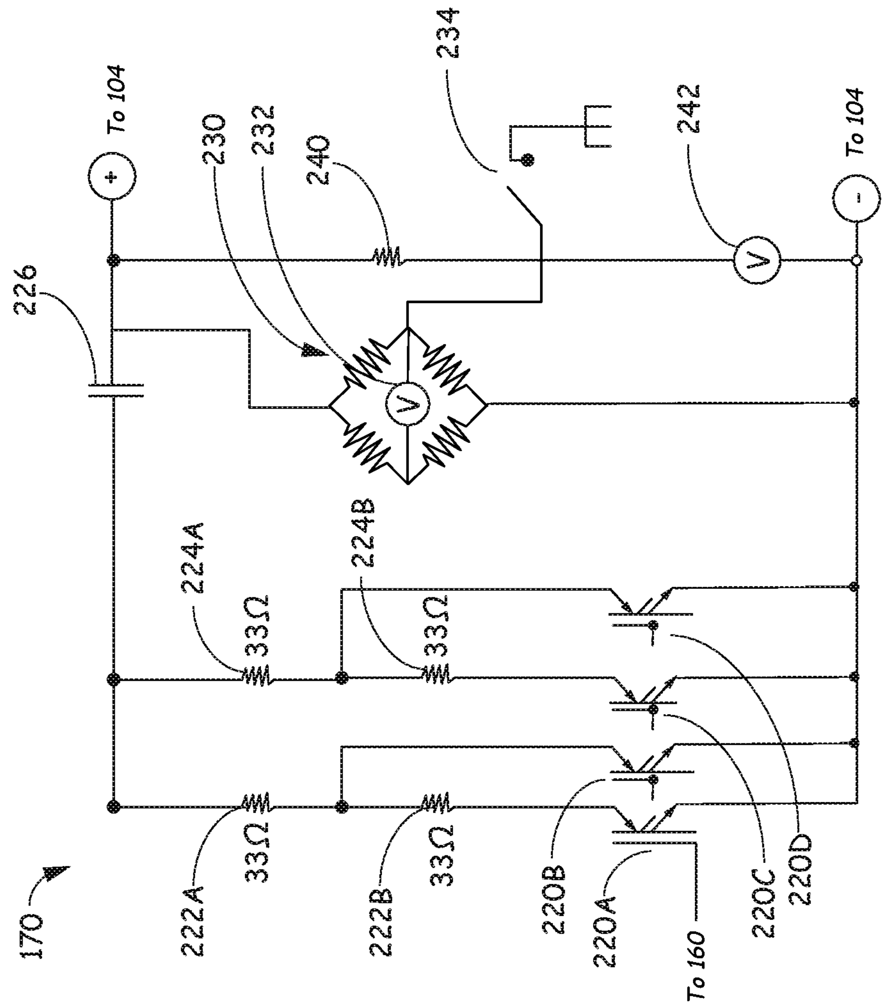

170
222A
33Ω
222B
33Ω
220B
220A
To 160
220C
220D
224A
33Ω
224B
33Ω
226
230
232
240
234
242
To 104
To 104
+
-
V
V

Fig. 3

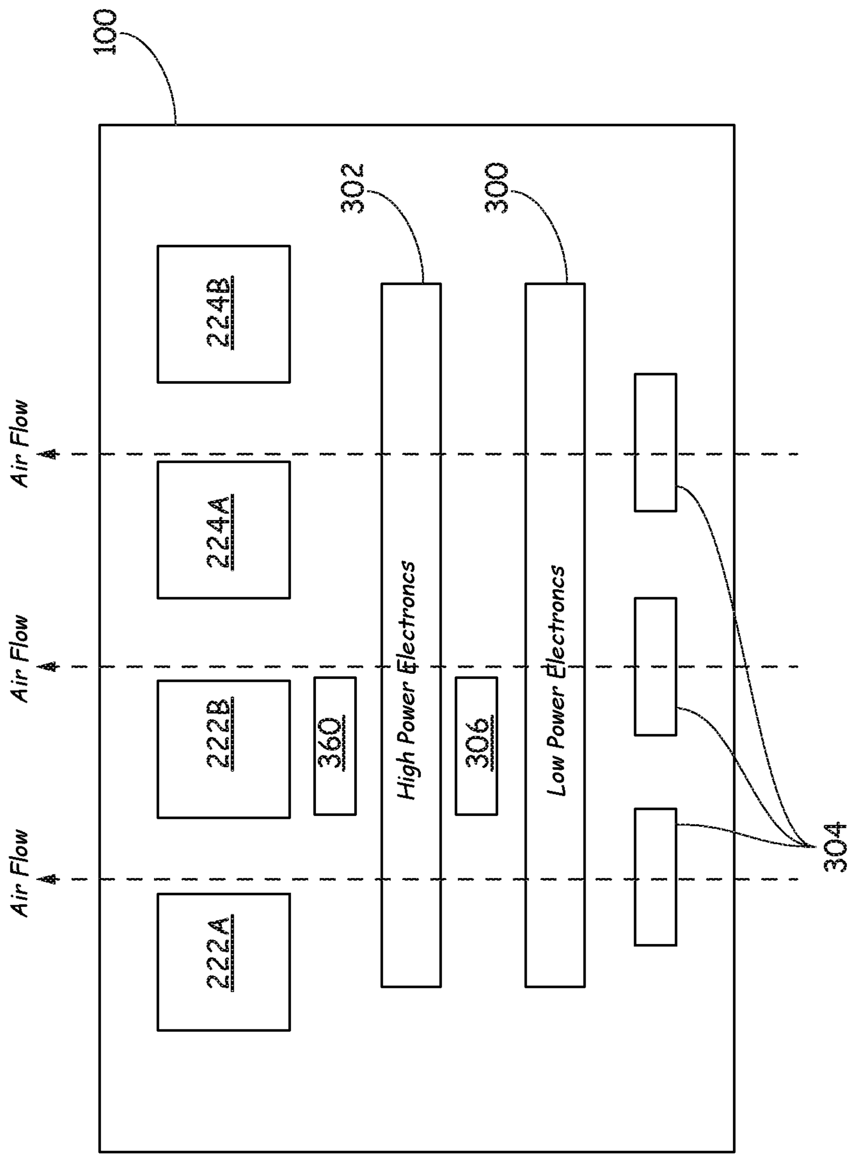

100
302
300
224B
224A
222B
222A
360
306
High Power Electroncs
Low Power Electroncs
Air Flow
Air Flow
Air Flow
304

Fig. 4

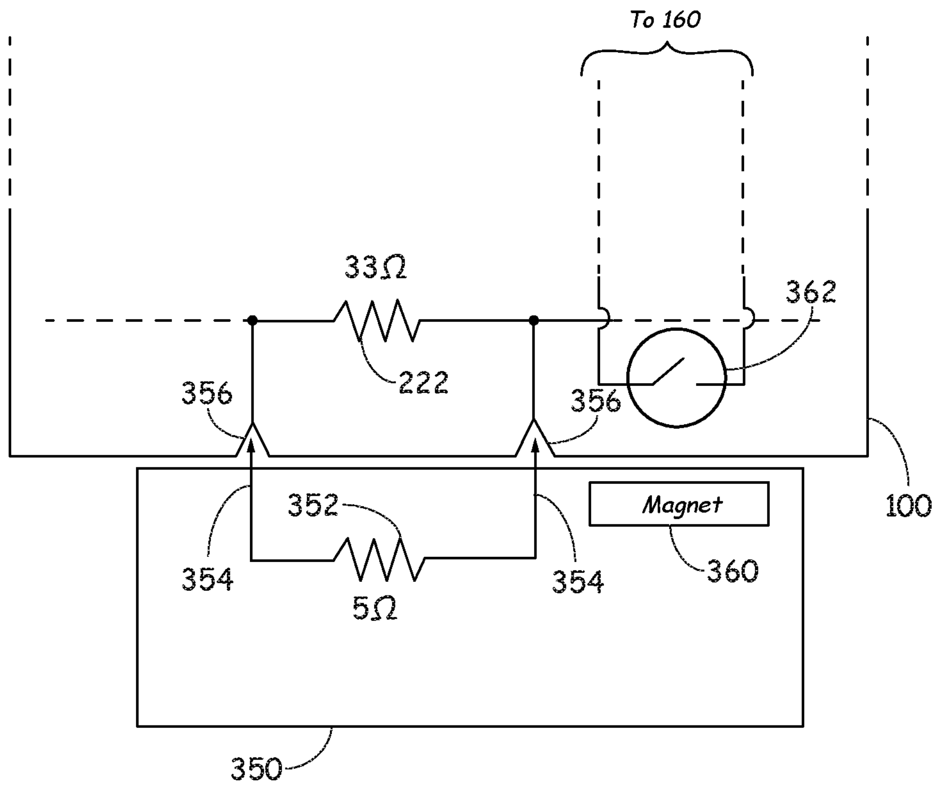



Fig. 5

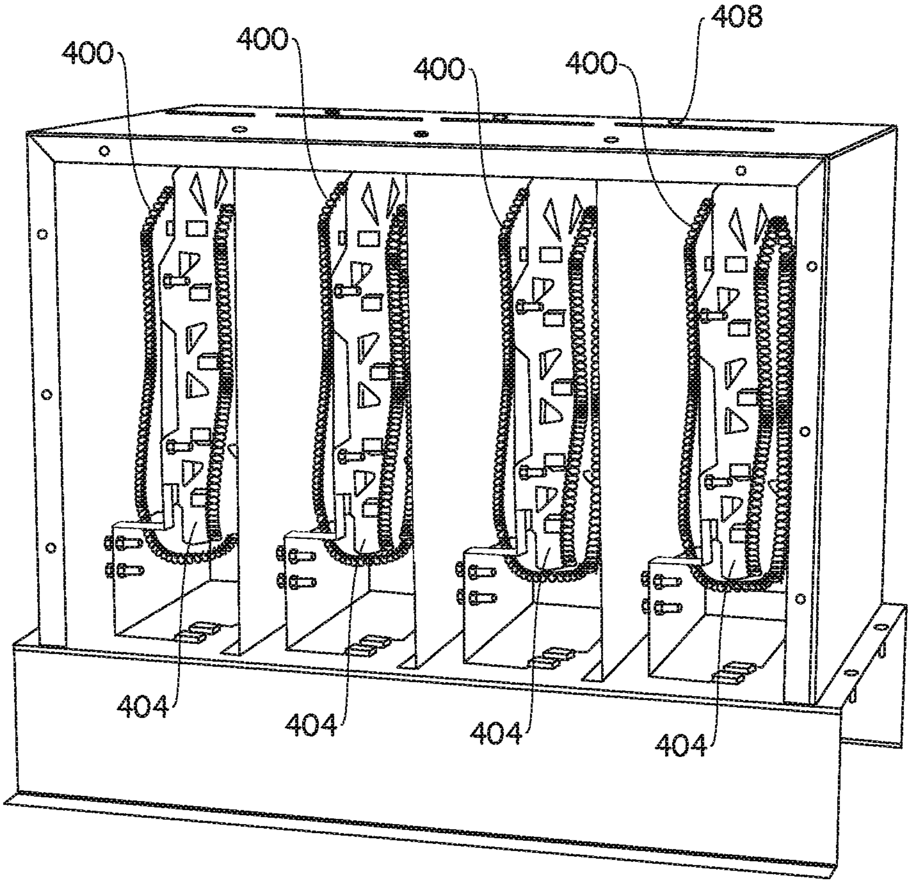



Fig. 6

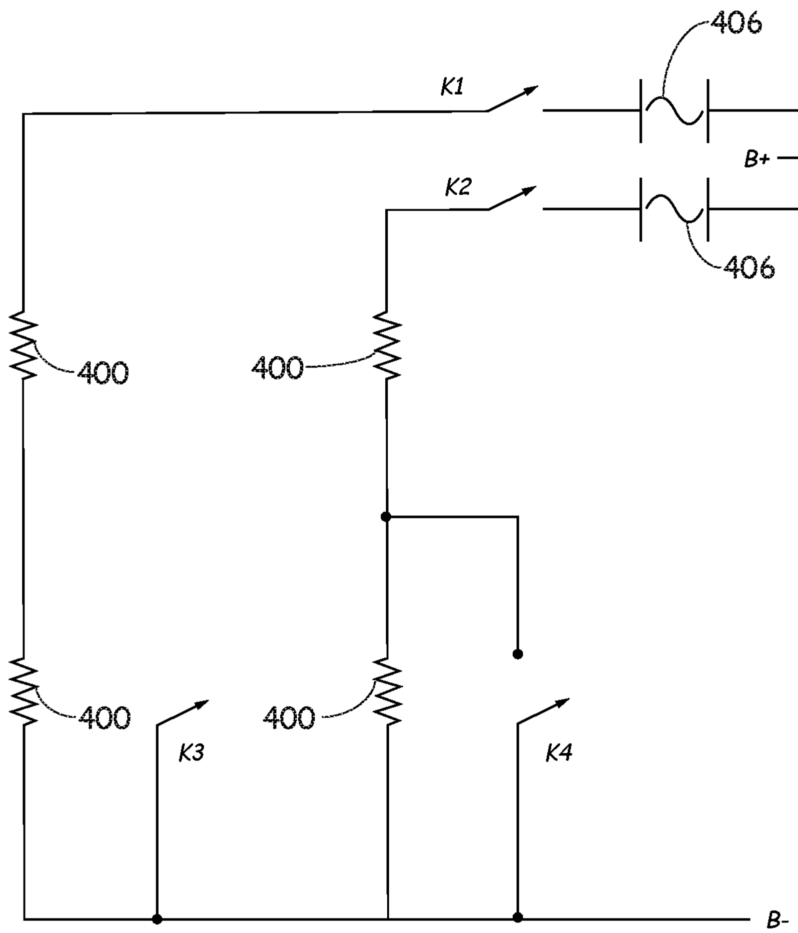



Fig. 7

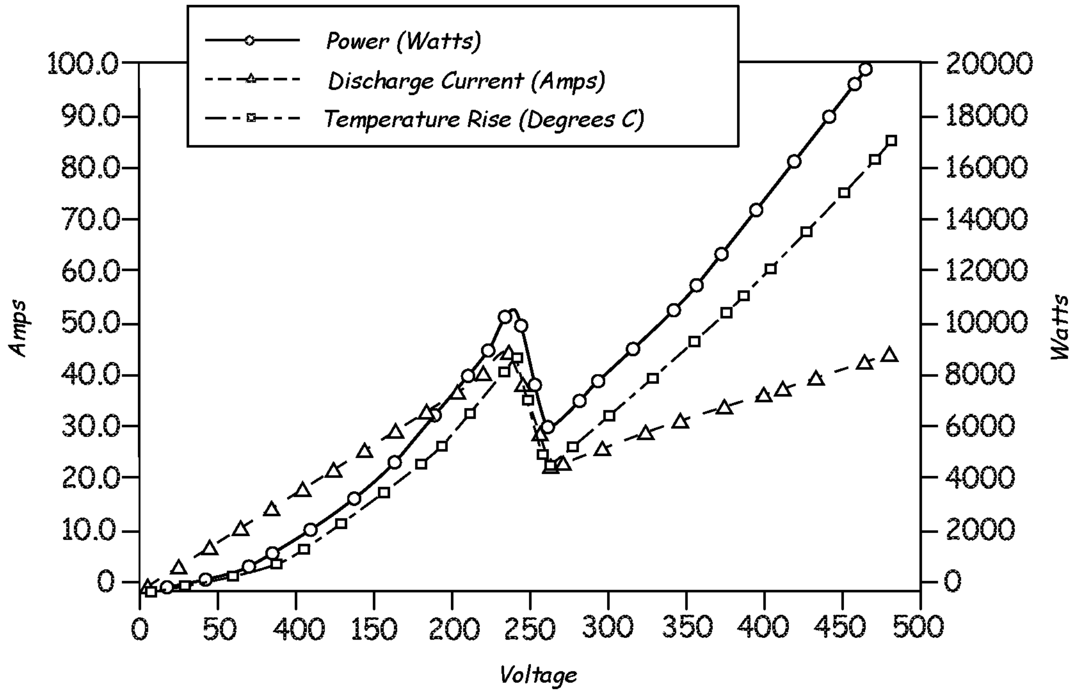
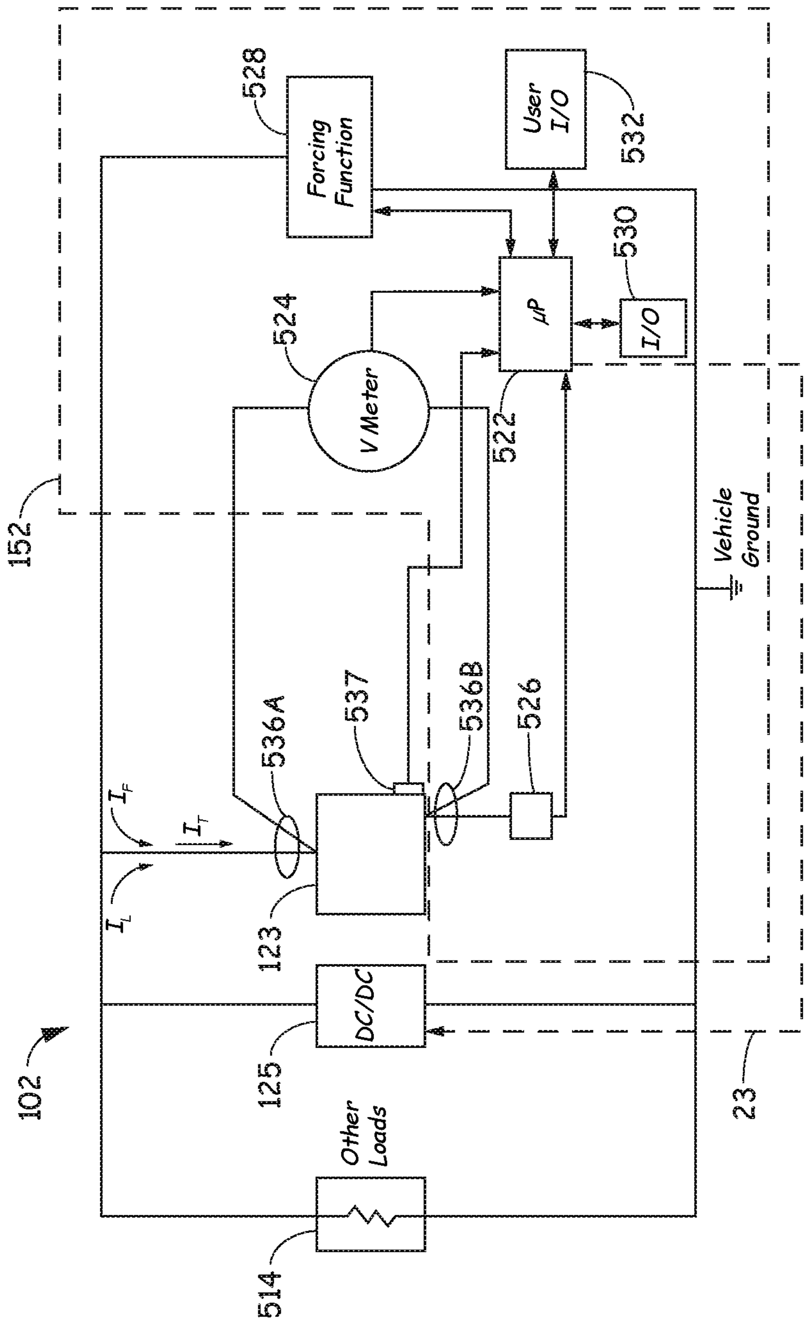

Power (Watts)
Discharge Current (Amps)
Temperature Rise (Degrees C)
Amps
Watts
Voltage
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
50
400
150
200
250
300
350
400
450
500

Fig. 8



528
Forcing Function
User I/O
532
530
524
µP
I/O
V Meter
522
152
Vehicle Ground
537
536A
536B
526
$I_F$
$I_T$
$I_L$
123
DC/DC
125
102
23
Other Loads
514


Fig. 9

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/033558

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. H01M10/42 H01M10/48 H02J7/00 B60L3/00 B60L58/10
G01R27/00 G01R31/36 G01R31/385 G01R31/52
ADD.

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
H02J H01M B60L G01R

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

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

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | WO 2022/241800 A1 (HUAWEI TECH CO LTD [CN]) 24 November 2022 (2022-11-24) | 1-5,7, 9-18,20, 22-26 |
| A | figures 1-4<br>paragraphs [0108] - [0140]<br>----- | 6,8,19, 21 |
| X | US 2003/025481 A1 (BERTNESS KEVIN I [US]) 6 February 2003 (2003-02-06)<br>figures 1-7<br>paragraphs [0024] - [0048]<br>----- | 1-26 |
| A | US 2021/141043 A1 (BERTNESS KEVIN I [US]) 13 May 2021 (2021-05-13)<br>figures 1-10<br>----- | 1-26 |

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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

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

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 31 July 2024 | 30/08/2024 |

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

# INTERNATIONAL SEARCH REPORT

**Information on patent family members**

International application No
PCT/US2024/033558

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
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| | | EP 4335681 A1 | 13-03-2024 |
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| | | US 2003025481 A1 | 06-02-2003 |
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| | | KR 20210057682 A | 21-05-2021 |
| | | US 2021141043 A1 | 13-05-2021 |