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(12) **United States Patent**
Mao et al.

(10) **Patent No.: US 9,425,492 B2**
(45) **Date of Patent: Aug. 23, 2016**

(54) **ENERGY SOURCE SYSTEMS HAVING DEVICES WITH DIFFERENTIAL STATES OF CHARGE**

(75) Inventors: **Ou Mao**, Mequon, WI (US); **Qi Zhang**, Milwaukee, WI (US); **Thomas M. Watson**, Milwaukee, WI (US); **Junwei Jiang**, Glendale, WI (US)

(73) Assignee: **Johnson Controls Technology Company**, Holland, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 732 days.

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(65) **Prior Publication Data**

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Related U.S. Application Data

(60) Provisional application No. 61/453,474, filed on Mar. 16, 2011, provisional application No. 61/477,730, filed on Apr. 21, 2011, provisional application No. 61/508,621, filed on Jul. 16, 2011, provisional application No. 61/508,622, filed on Jul. 16, 2011.

(51) **Int. Cl.**
H01M 16/00 (2006.01)
H01M 2/10 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01M 16/00*** (2013.01); ***B60L 3/0046*** (2013.01); ***B60L 3/04*** (2013.01); ***B60L 11/005*** (2013.01); ***B60L 11/14*** (2013.01); ***B60L 11/1859*** (2013.01); ***B60L 11/1866*** (2013.01); ***B60L 11/1877*** (2013.01); ***B60L 11/1879*** (2013.01); ***H01M 2/1072*** (2013.01); ***H01M 10/052*** (2013.01); ***H01M 10/06*** (2013.01); ***H01M 10/4257*** (2013.01); ***H01M 10/4264*** (2013.01); ***H01M 10/441*** (2013.01); ***H02J 7/0021*** (2013.01); ***H02J 7/0031*** (2013.01); ***H02J 7/1423*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H01M 10/4257
USPC 320/112
See application file for complete search history.

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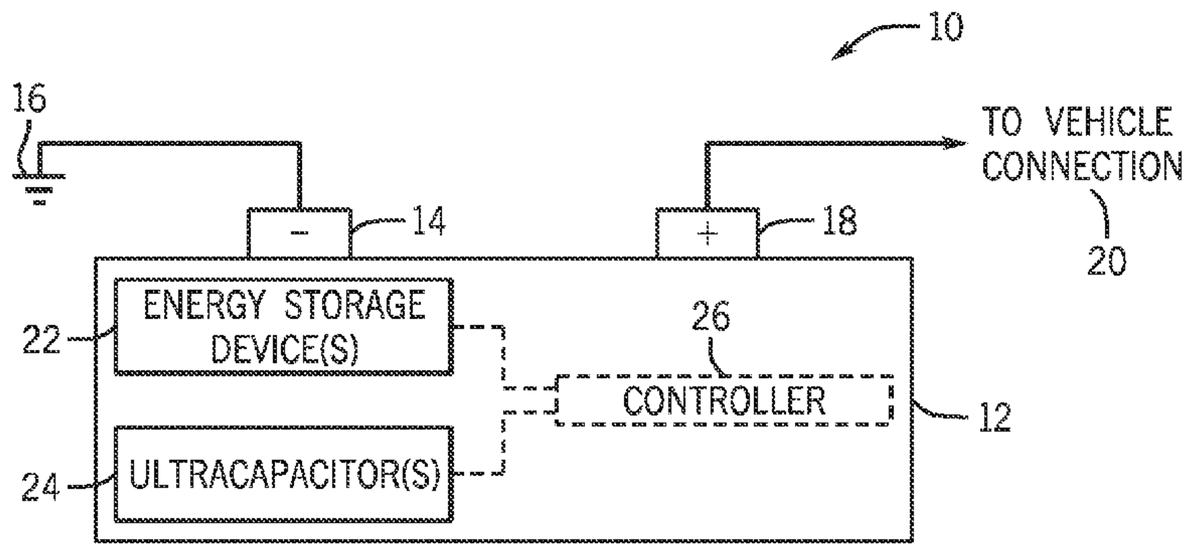
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Primary Examiner — Drew A Dunn
Assistant Examiner — Jerry D Robbins
(74) *Attorney, Agent, or Firm* — Fletcher Yoder, P.C.

(57) **ABSTRACT**

A system includes housing having a positive terminal and a negative terminal and one or more energy storage devices disposed therein. One system includes a first energy storage device that operates at a first state of charge level and a second energy storage device that operates at a second state of charge level. The second state of charge level is greater than the first state of charge level.

7 Claims, 10 Drawing Sheets



(51) **Int. Cl.**

H01M 10/052	(2010.01)
H01M 10/06	(2006.01)
H01M 10/42	(2006.01)
H01M 10/44	(2006.01)
H02J 7/14	(2006.01)
H02J 7/34	(2006.01)
B60L 3/00	(2006.01)
B60L 3/04	(2006.01)
B60L 11/00	(2006.01)
B60L 11/14	(2006.01)
B60L 11/18	(2006.01)
H02J 7/00	(2006.01)
H01G 11/14	(2013.01)

(52) **U.S. Cl.**

CPC ***H02J7/345*** (2013.01); *B60L 2210/10* (2013.01); *B60L 2240/547* (2013.01); *B60L 2240/549* (2013.01); *B60L 2240/662* (2013.01); *H01G 11/14* (2013.01); *H01M 2220/20* (2013.01); *Y02E 60/122* (2013.01); *Y02E 60/126* (2013.01); *Y02P 70/54* (2015.11); *Y02T 10/70* (2013.01); *Y02T 10/7005* (2013.01); *Y02T 10/7011* (2013.01); *Y02T 10/7016* (2013.01); *Y02T 10/7022* (2013.01); *Y02T 10/7055* (2013.01); *Y02T 10/7061* (2013.01); *Y02T 10/7077* (2013.01); *Y02T 10/7216* (2013.01); *Y02T 10/7291* (2013.01); *Y02T 90/16* (2013.01); *Y10T 29/49108* (2015.01); *Y10T 307/50* (2015.04)

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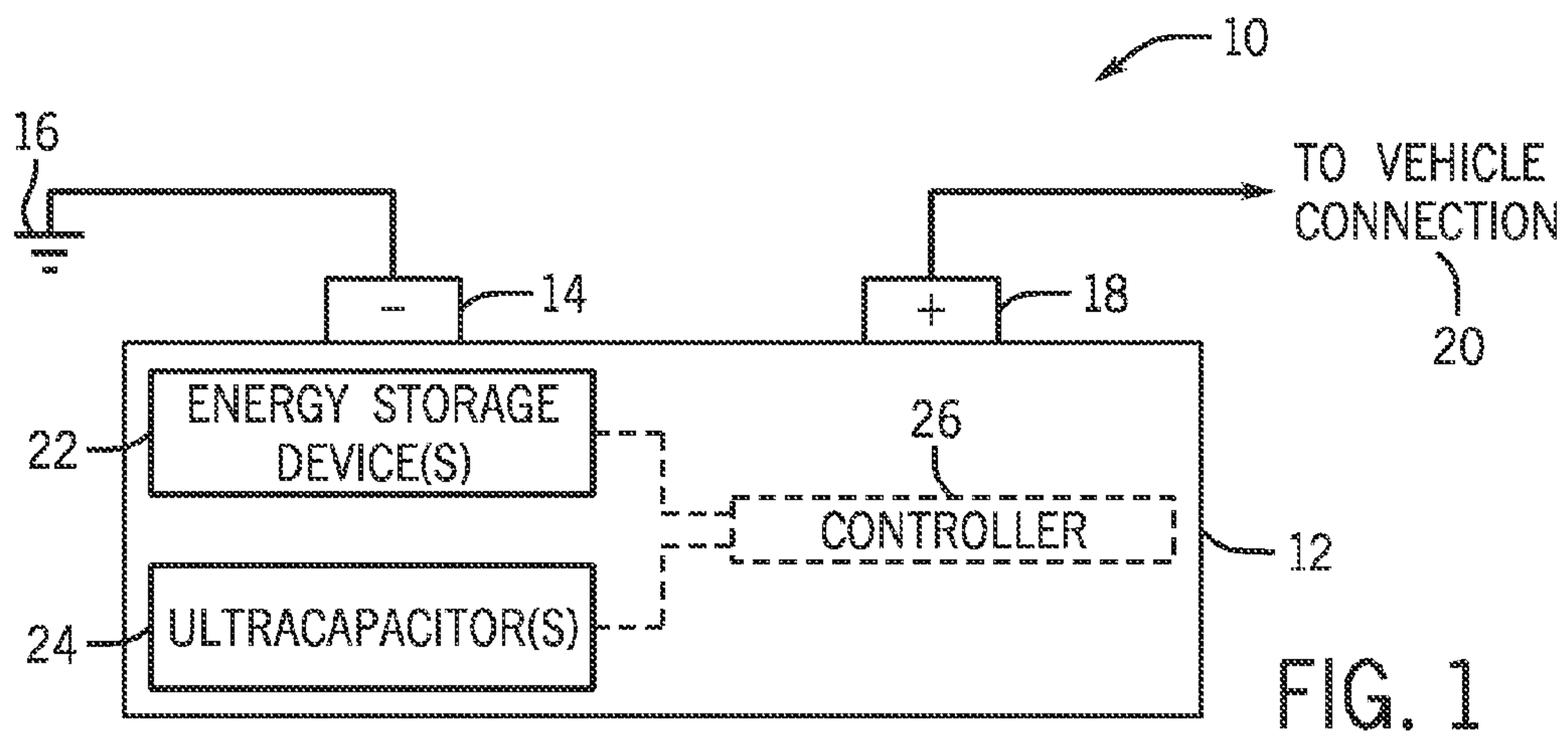


FIG. 1

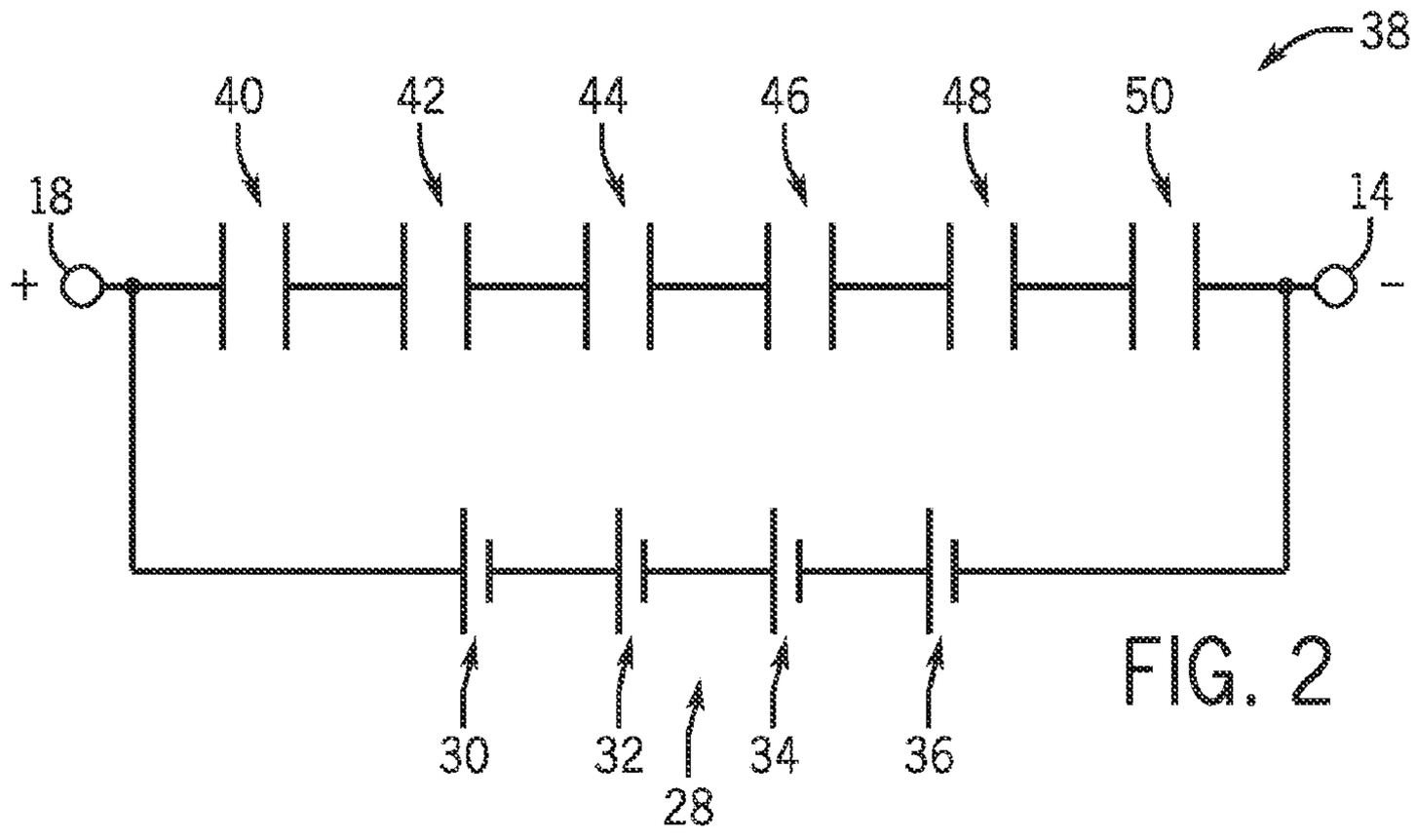


FIG. 2

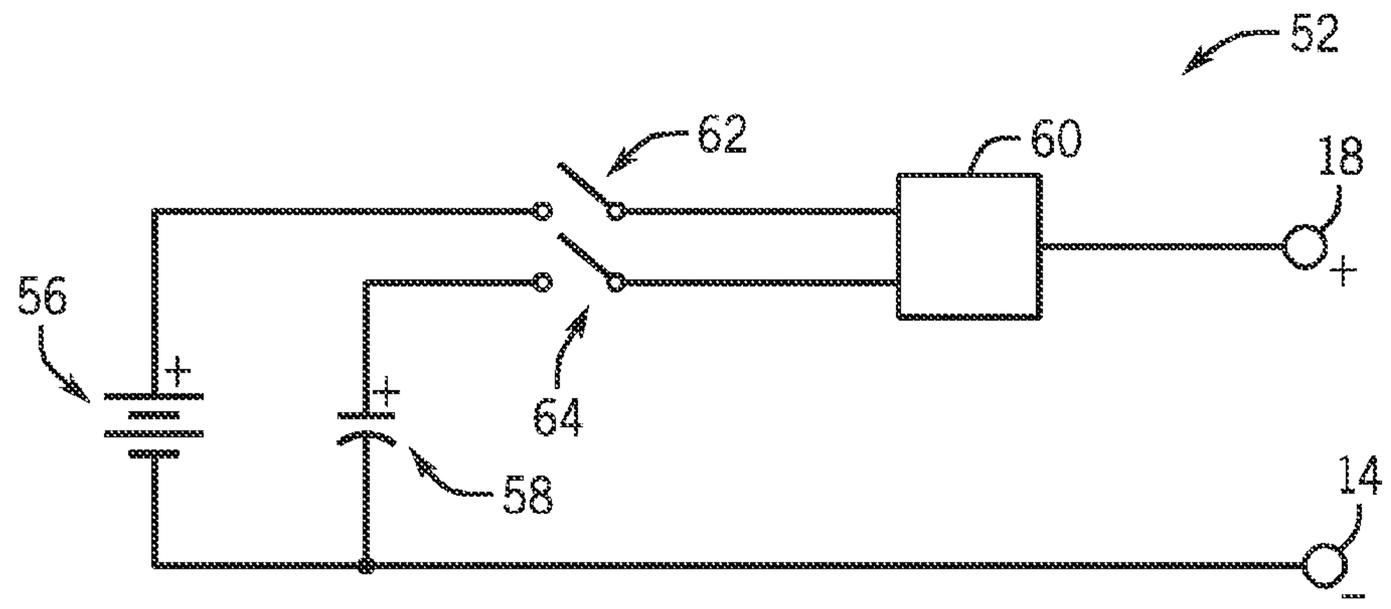


FIG. 3

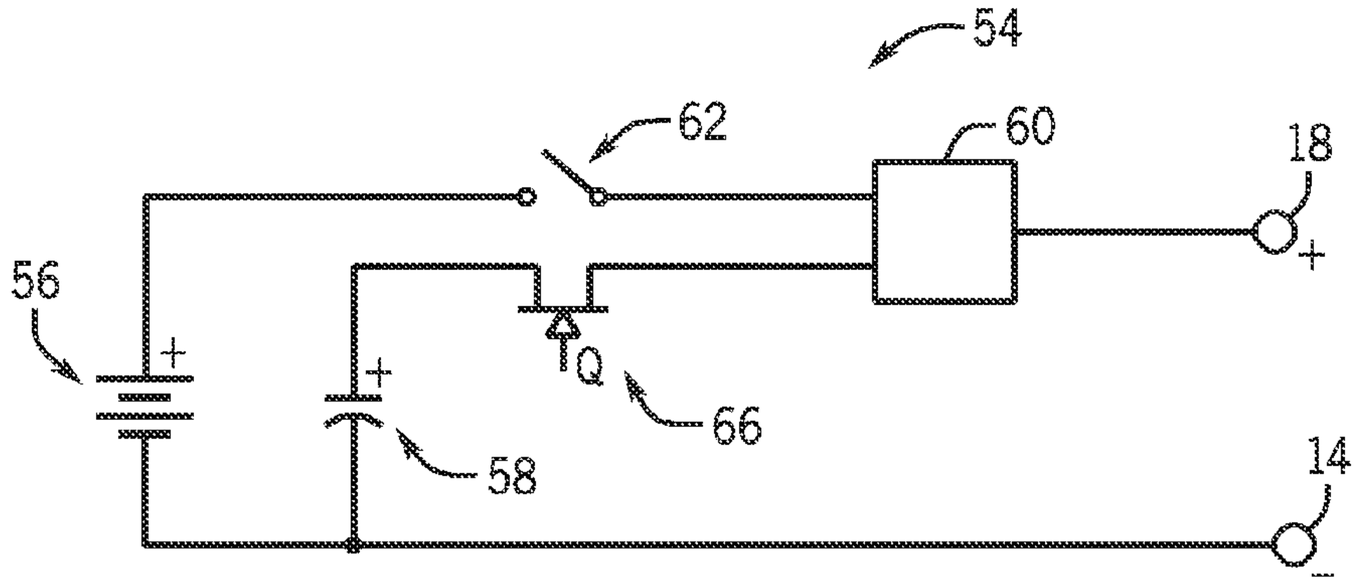

54
62
60
18
56
+
+
Q
66
58
14
-

FIG. 4

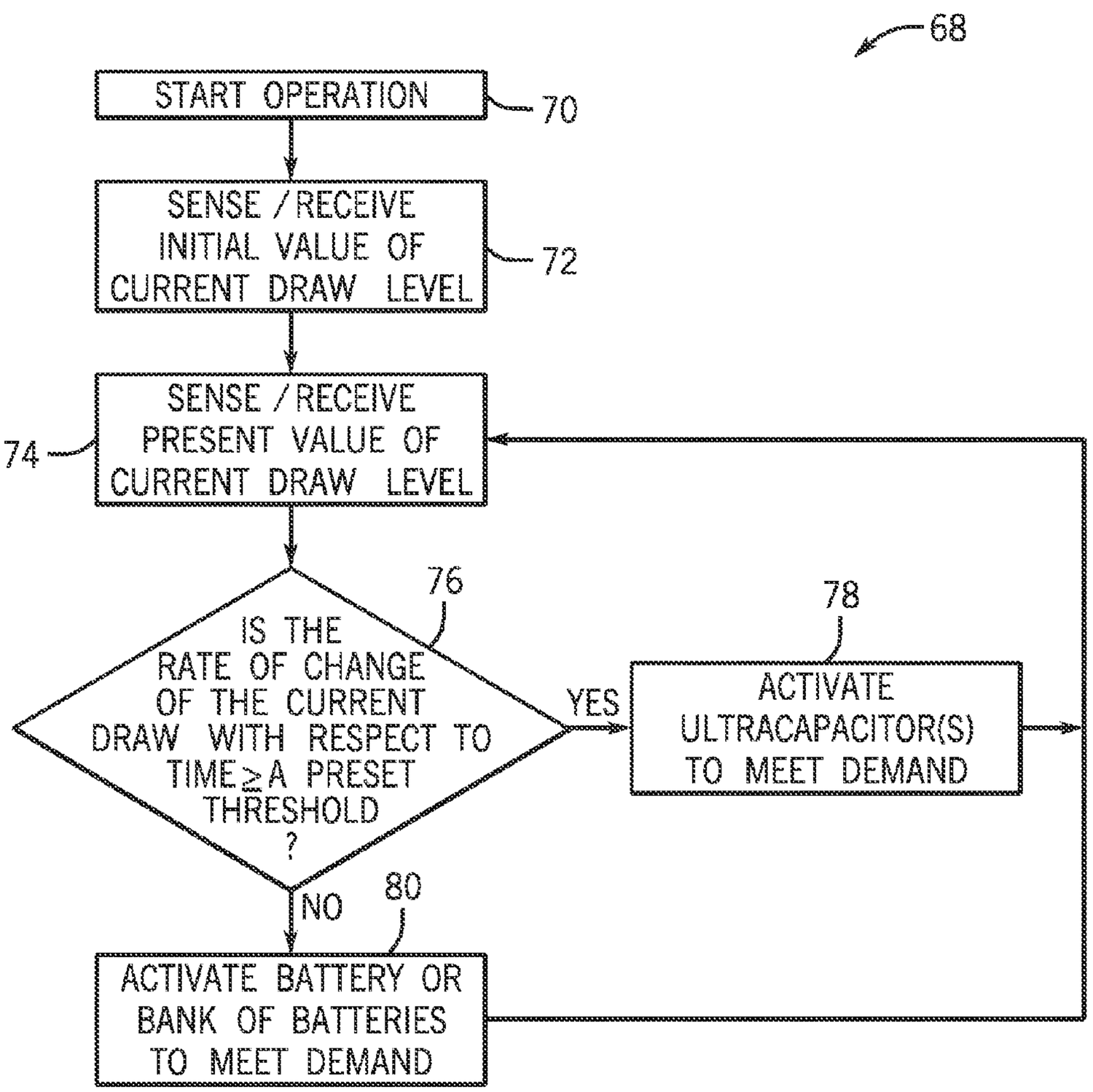

68
START OPERATION
70
SENSE / RECEIVE INITIAL VALUE OF CURRENT DRAW LEVEL
72
SENSE / RECEIVE PRESENT VALUE OF CURRENT DRAW LEVEL
74
76
IS THE RATE OF CHANGE OF THE CURRENT DRAW WITH RESPECT TO TIME ≥ A PRESET THRESHOLD ?
YES
78
ACTIVATE ULTRACAPACITOR(S) TO MEET DEMAND
NO
80
ACTIVATE BATTERY OR BANK OF BATTERIES TO MEET DEMAND

FIG. 5

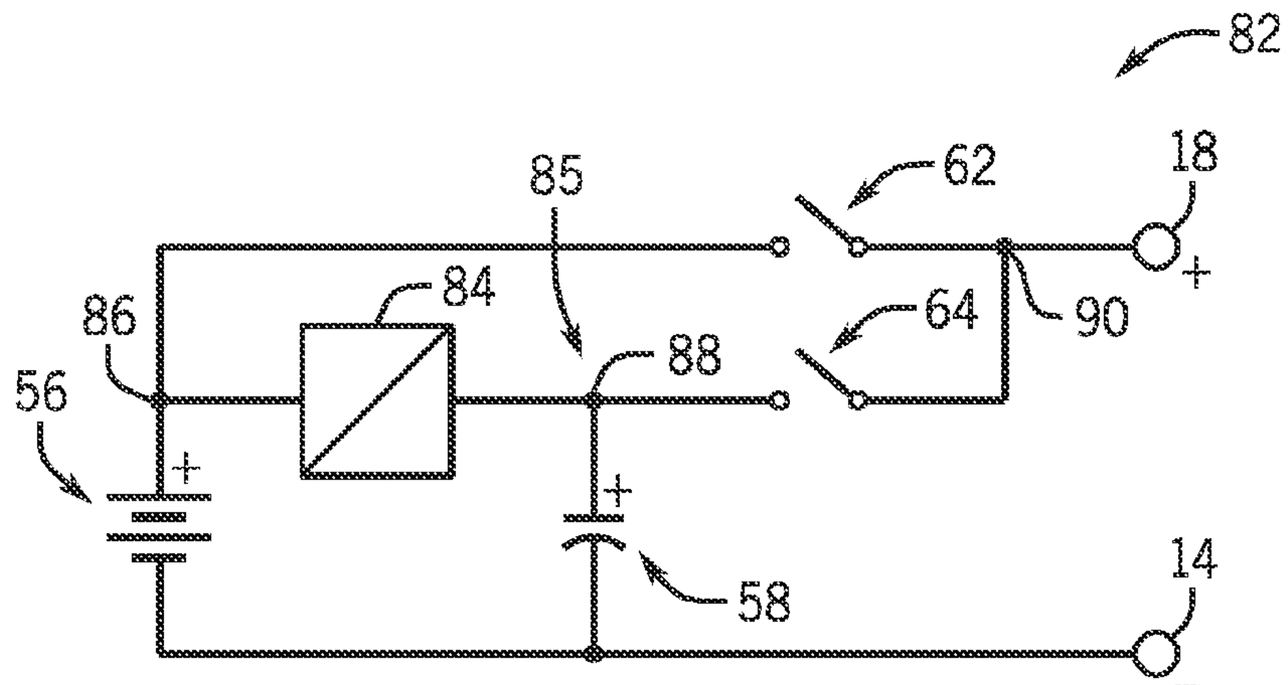

82
85
62
18
+
84
86
64
90
88
56
+
+
58
14

FIG. 6

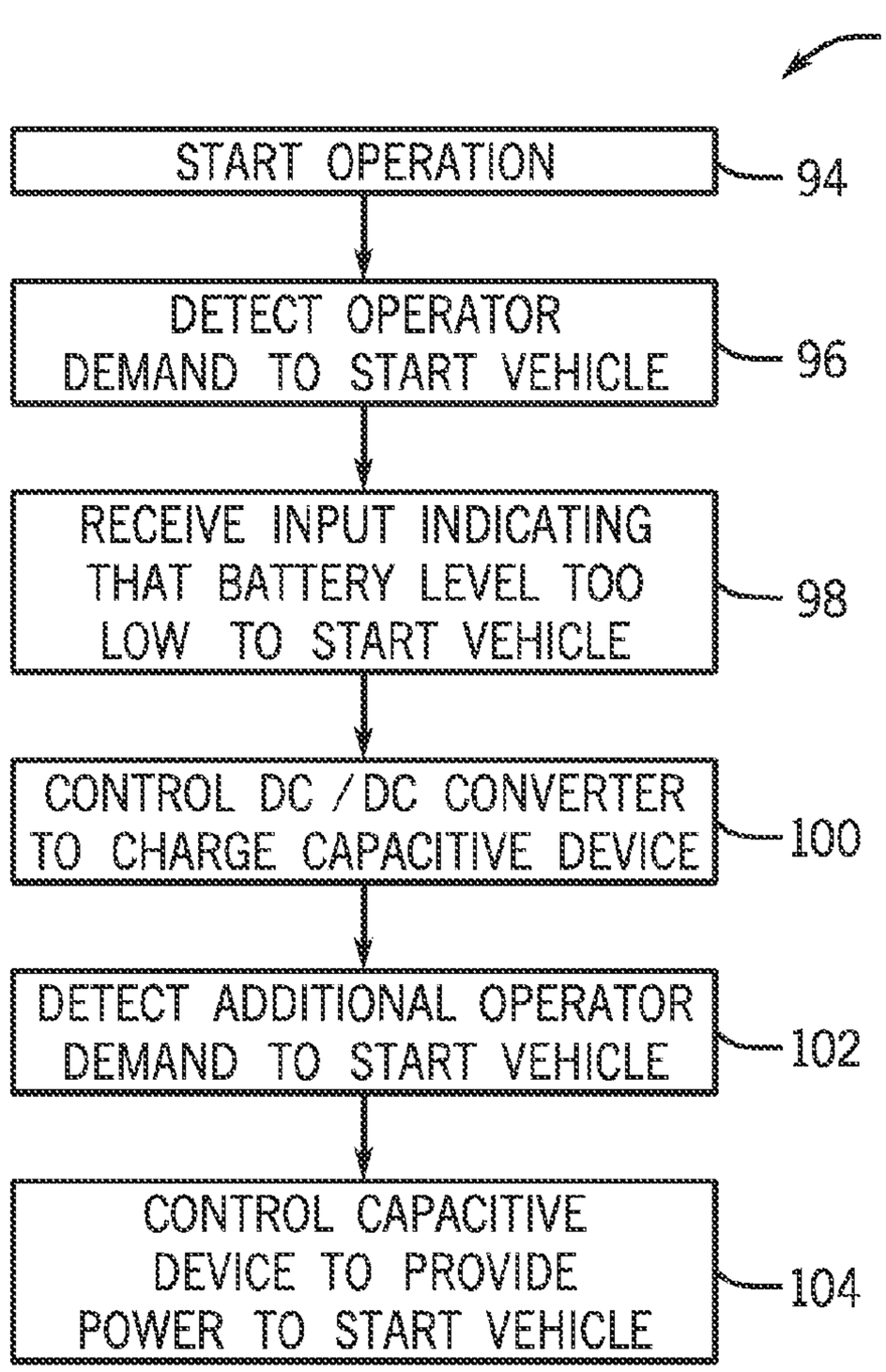

92
START OPERATION
94
DETECT OPERATOR DEMAND TO START VEHICLE
96
RECEIVE INPUT INDICATING THAT BATTERY LEVEL TOO LOW TO START VEHICLE
98
CONTROL DC / DC CONVERTER TO CHARGE CAPACITIVE DEVICE
100
DETECT ADDITIONAL OPERATOR DEMAND TO START VEHICLE
102
CONTROL CAPACITIVE DEVICE TO PROVIDE POWER TO START VEHICLE
104

FIG. 7

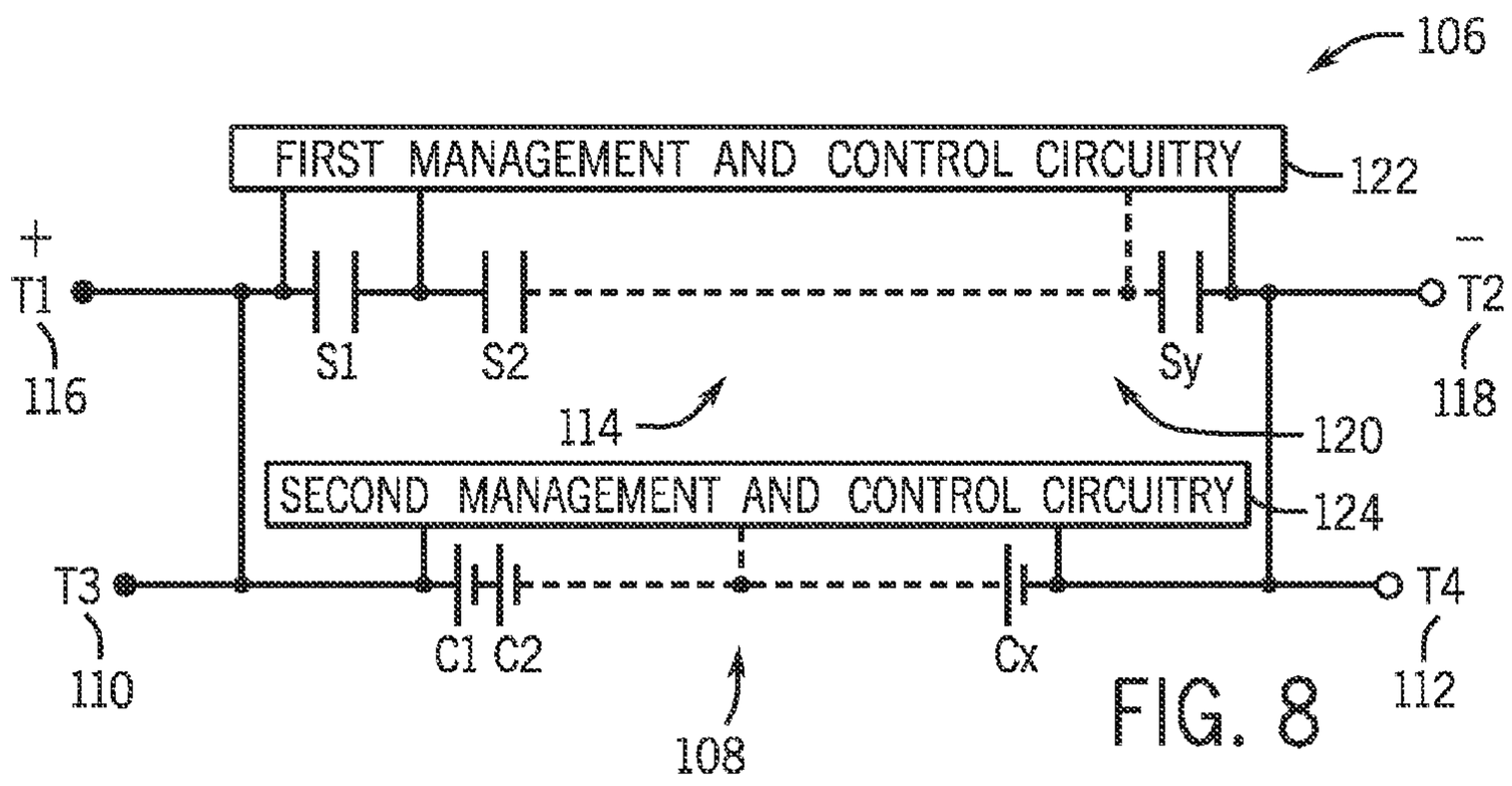


FIG. 8

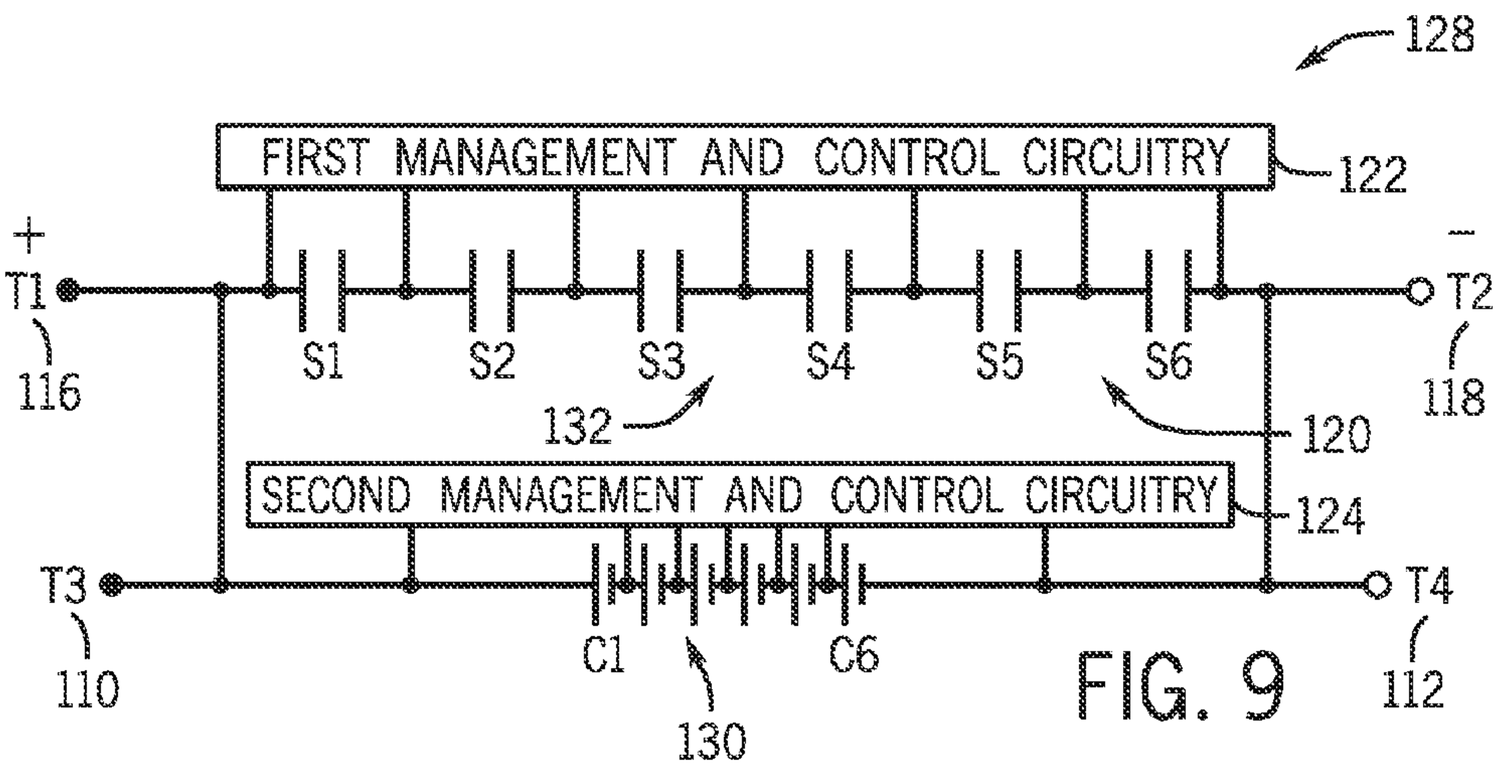


FIG. 9

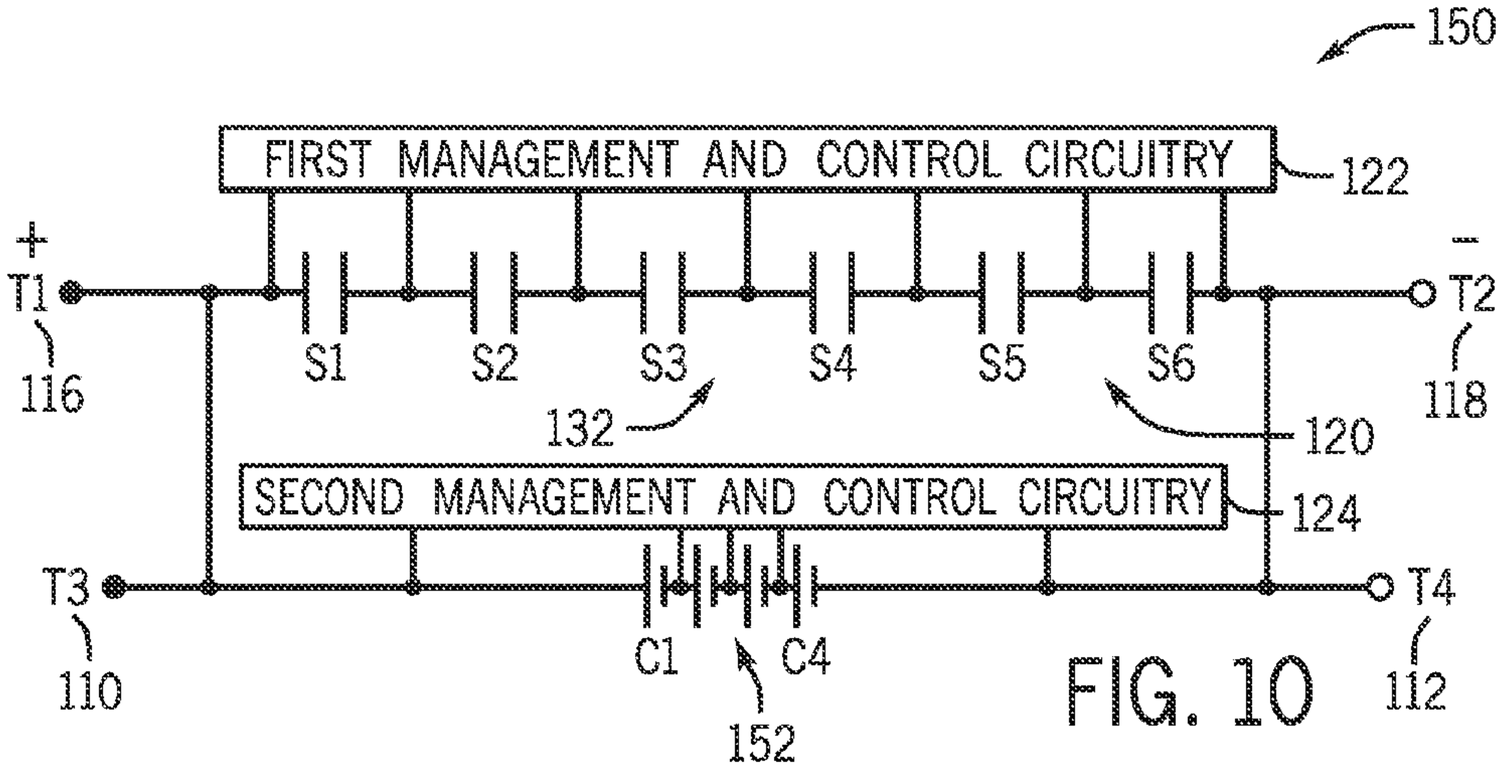


FIG. 10

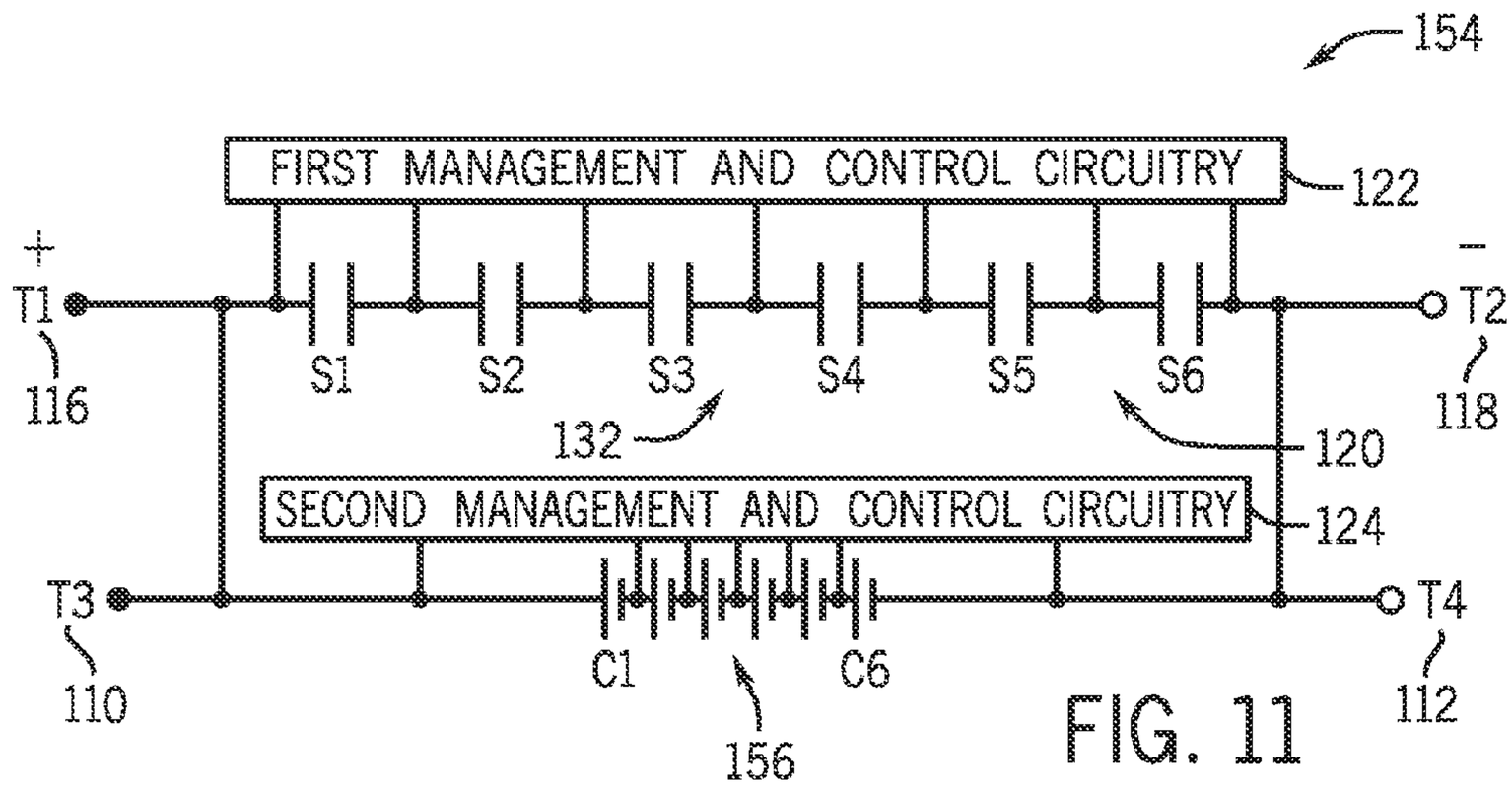


FIG. 11

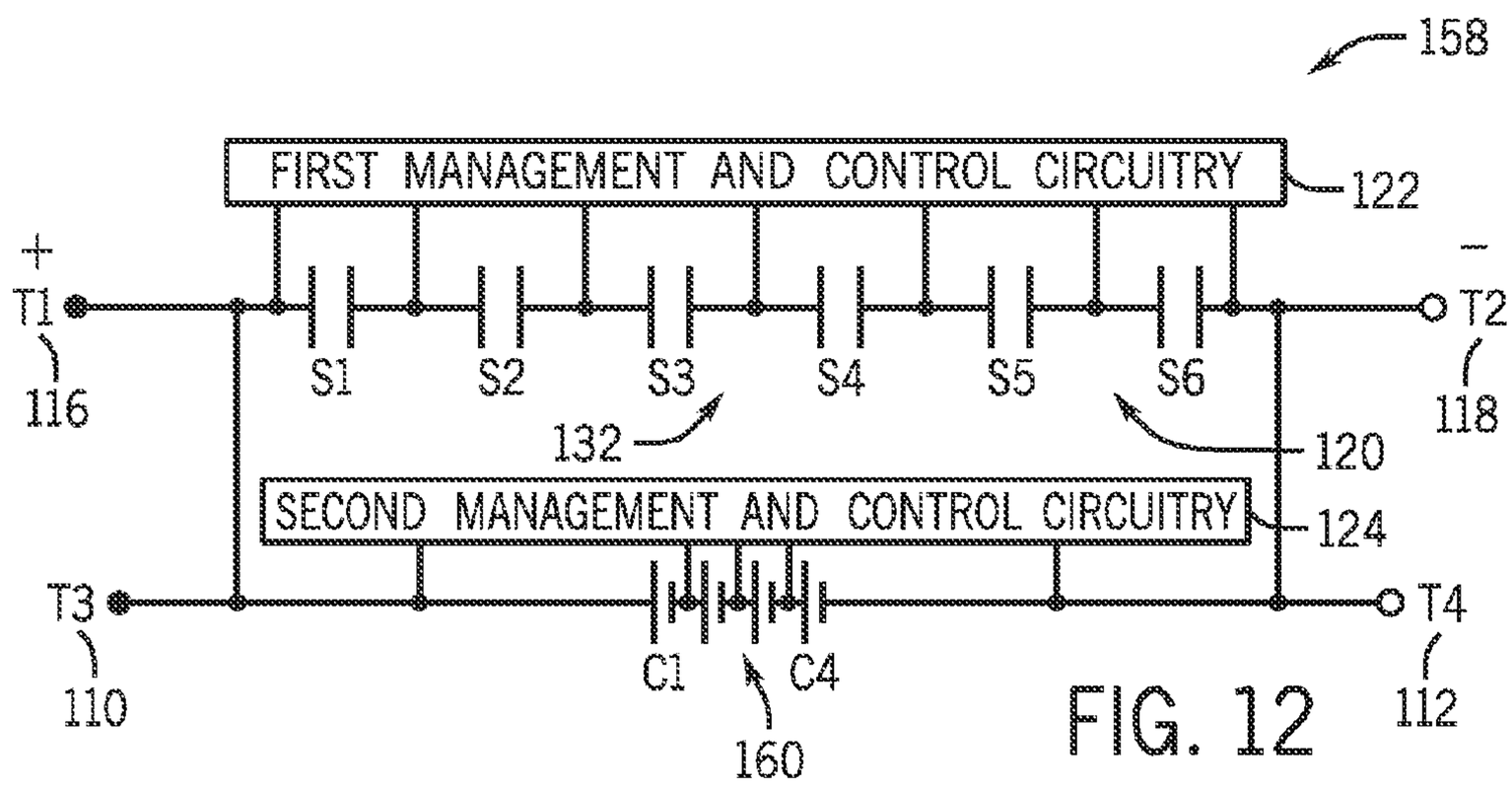


FIG. 12

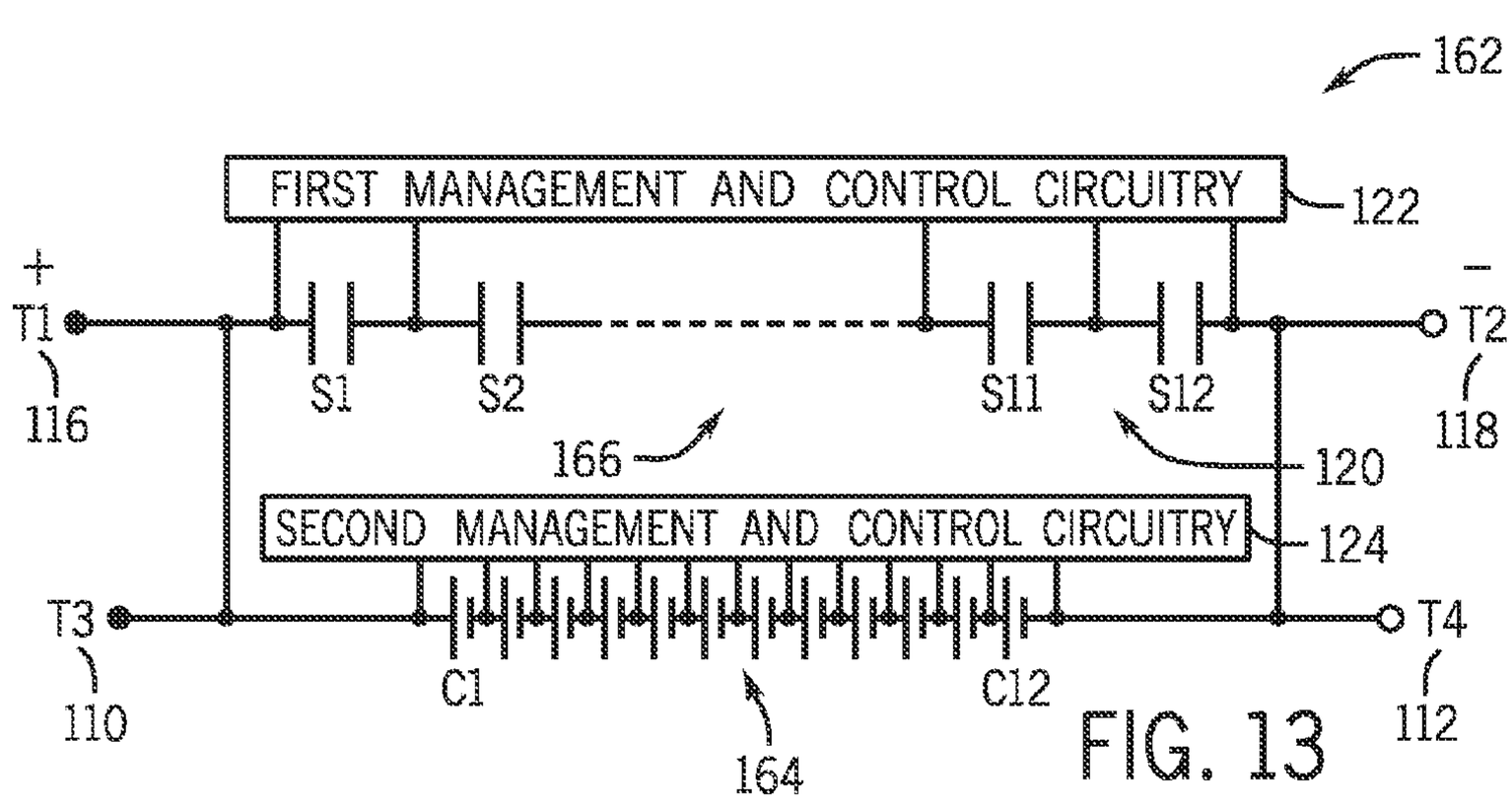


FIG. 13

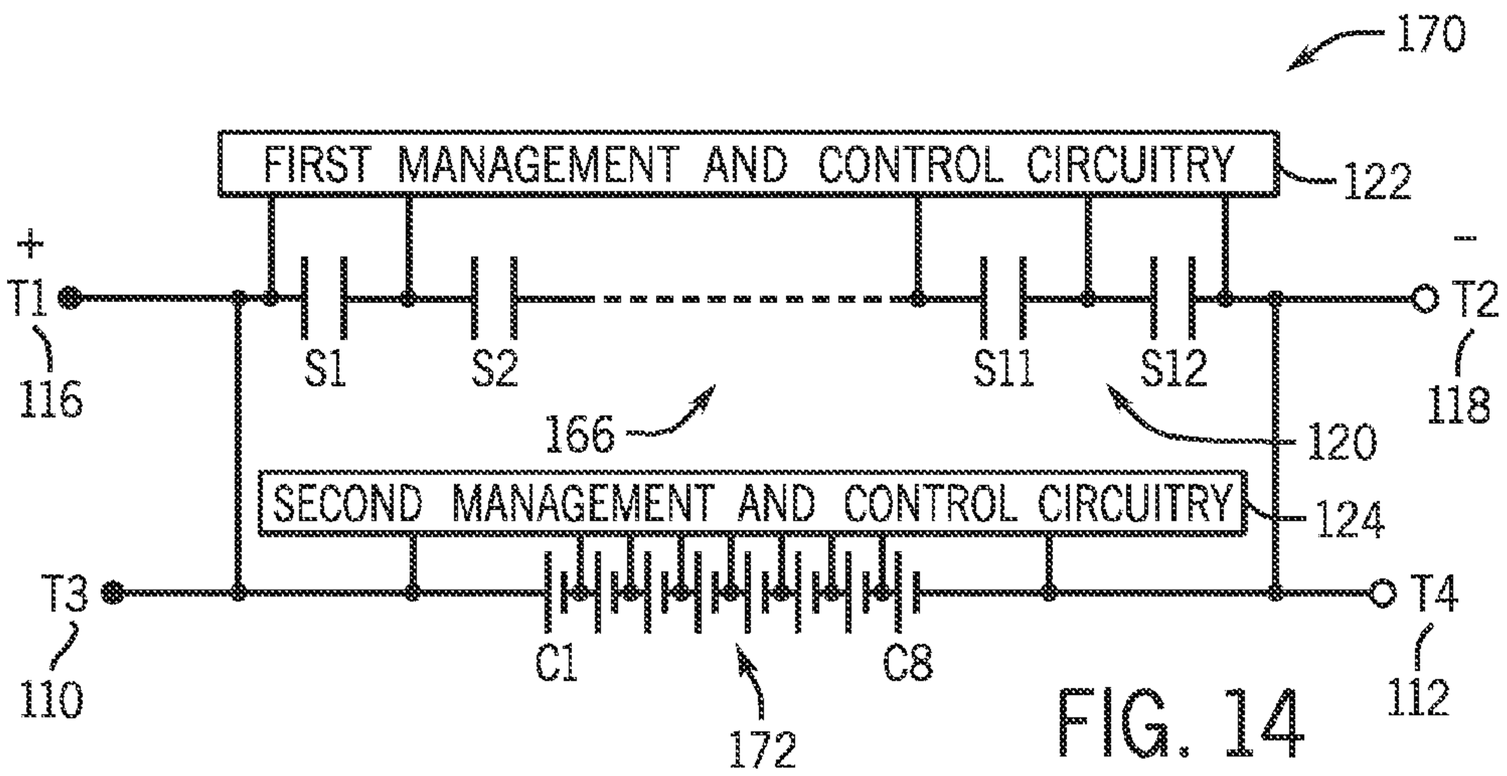


FIG. 14

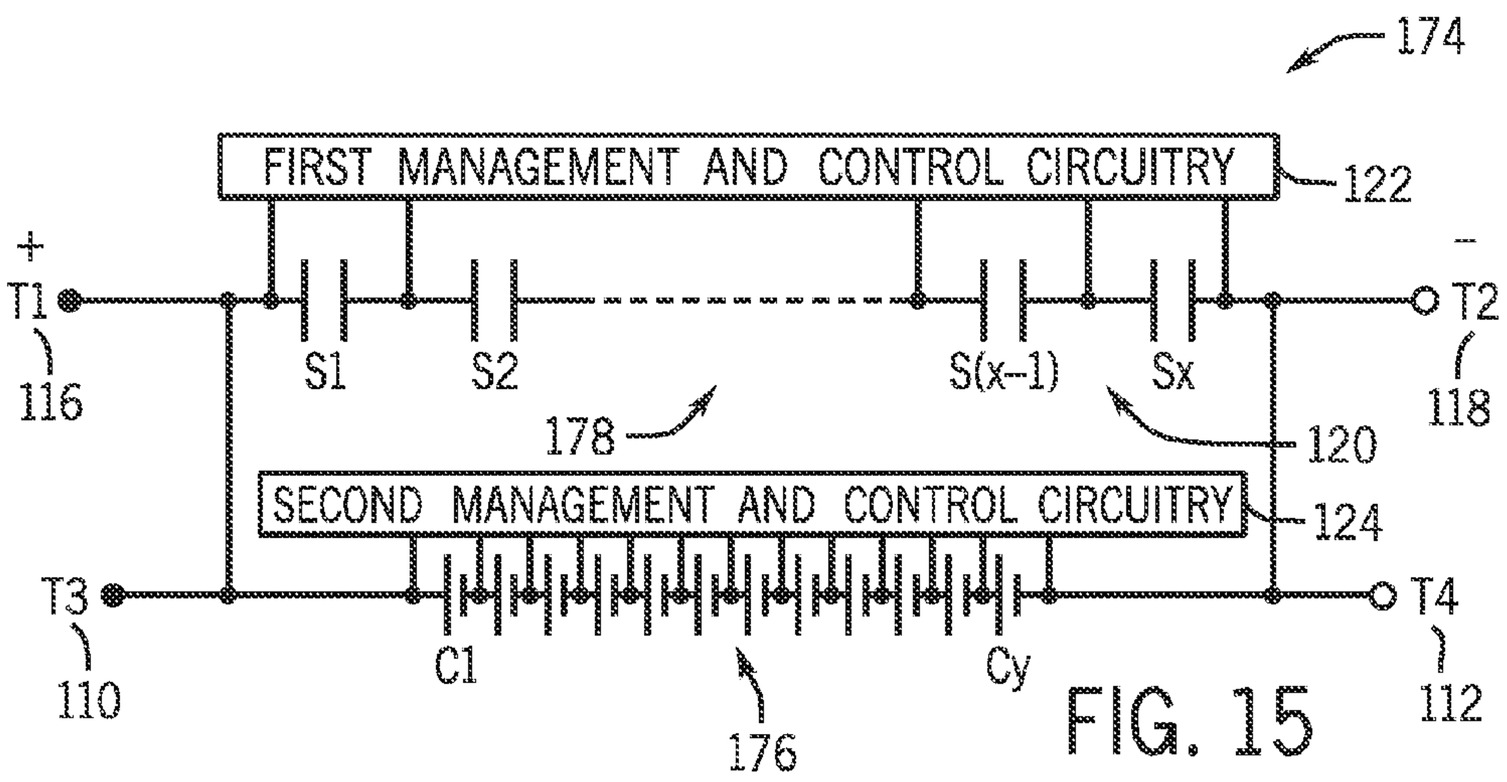


FIG. 15

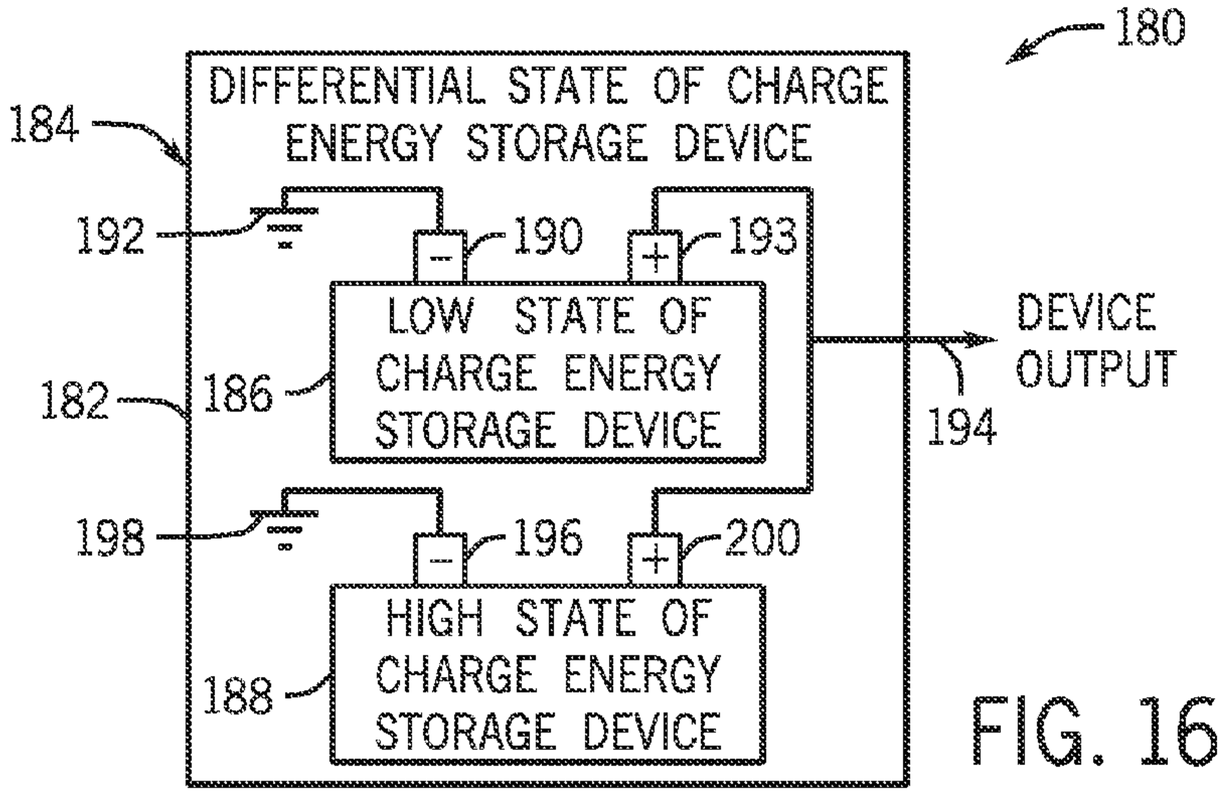


FIG. 16

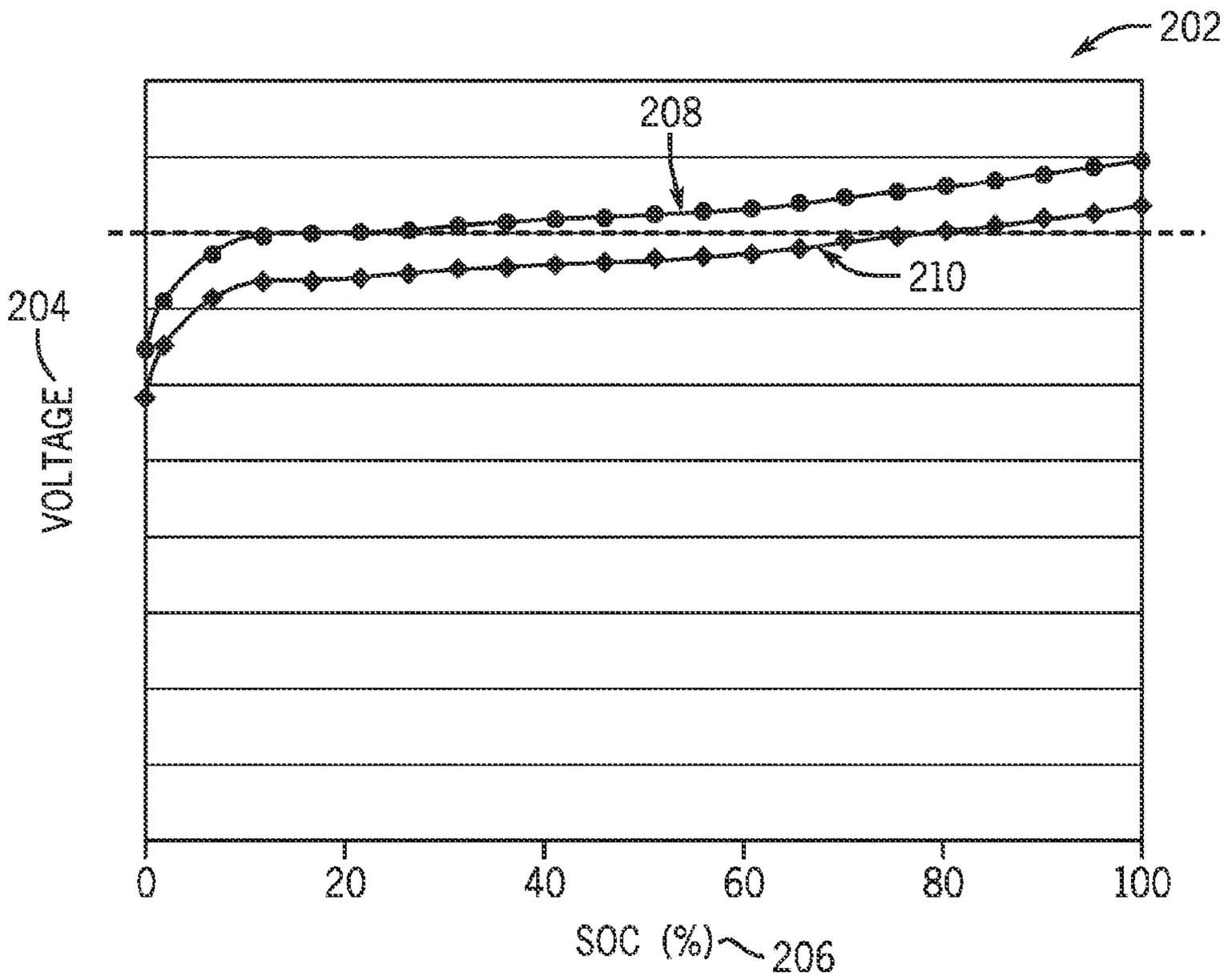

202
208
210
204
VOLTAGE
0
20
40
60
80
100
SOC (%)
206

FIG. 17

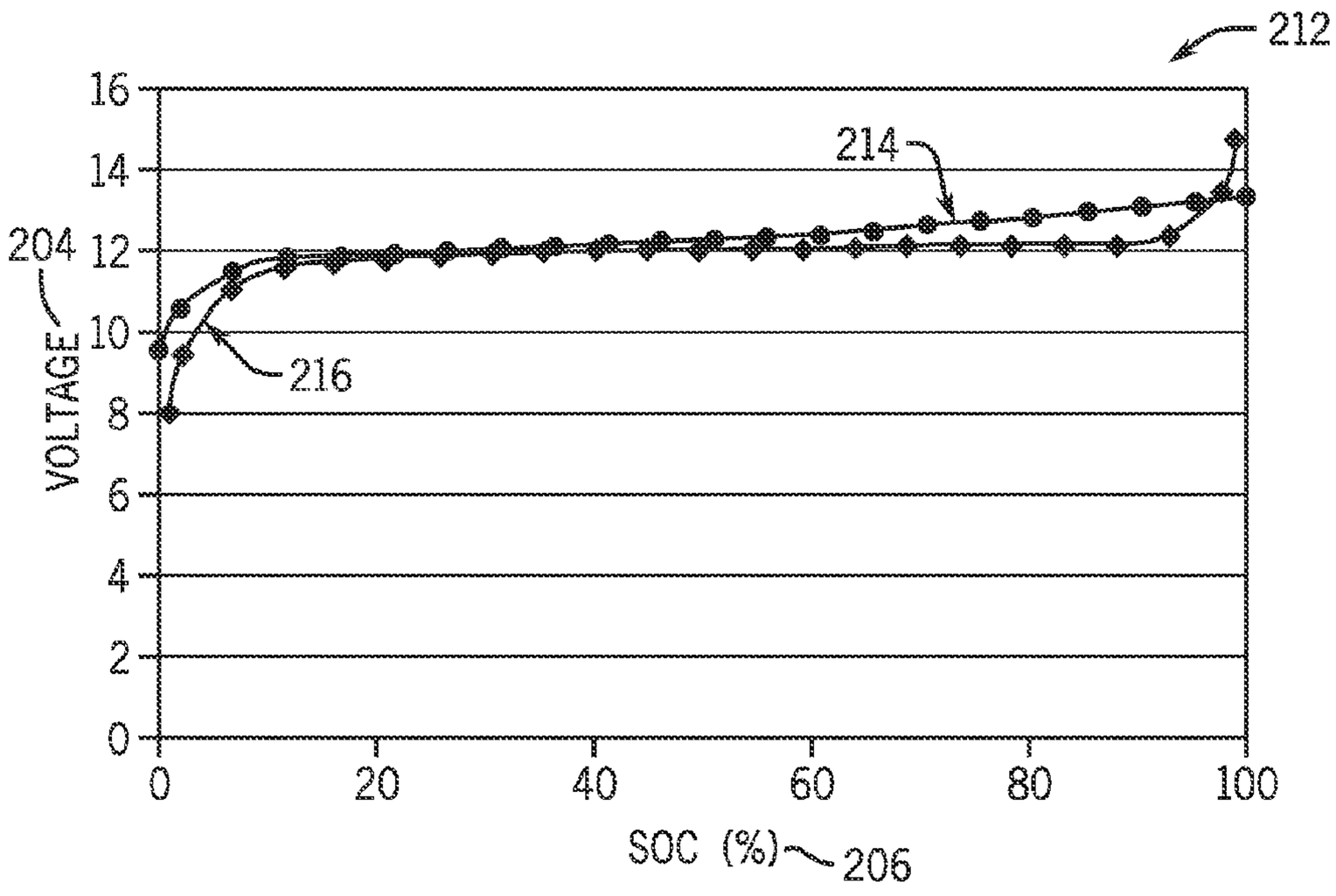

212
214
216
204
VOLTAGE
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
SOC (%)
206

FIG. 18

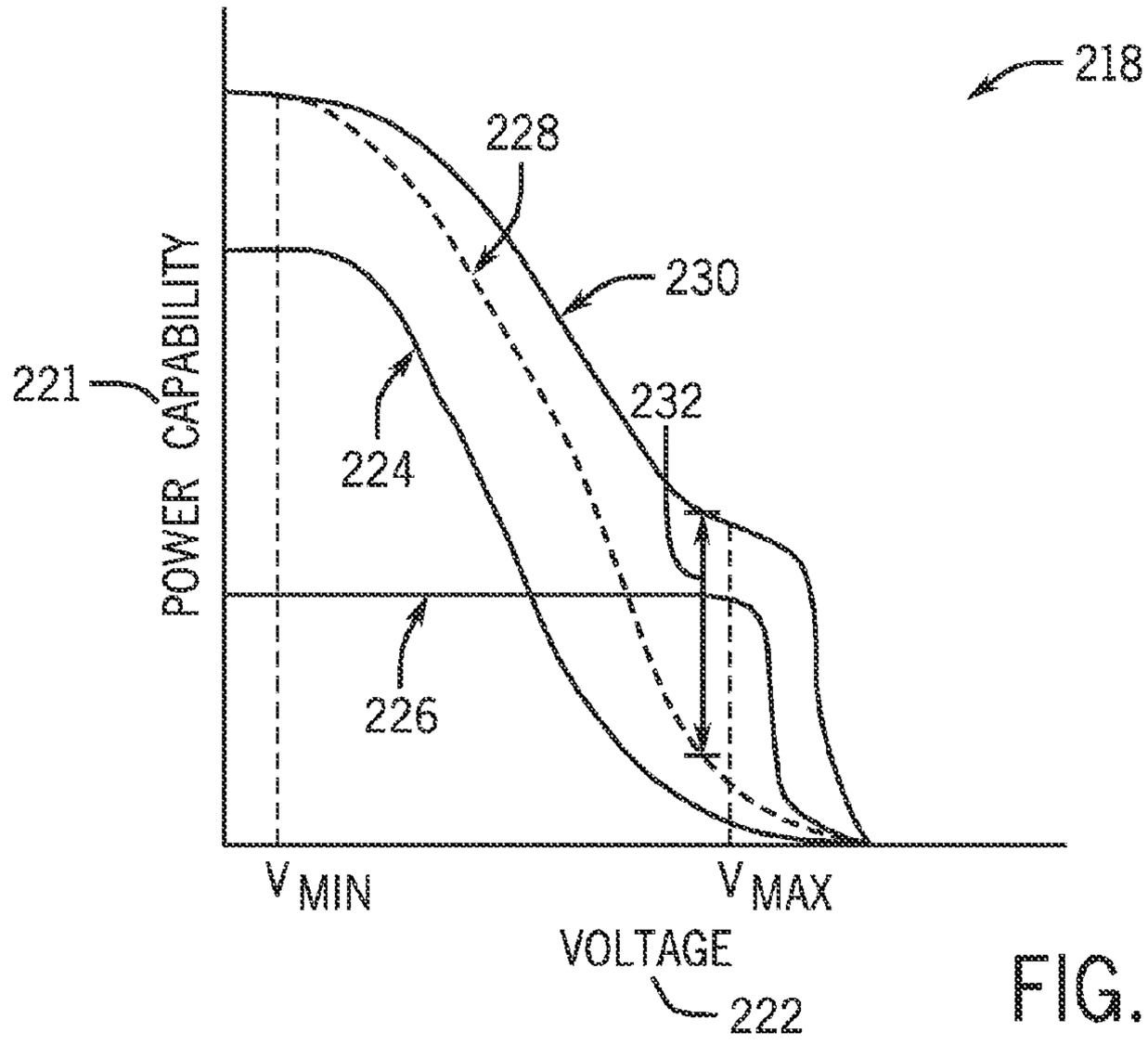

218
228
230
232
221
224
226
POWER CAPABILITY
V MIN
V MAX
VOLTAGE
222

FIG. 19

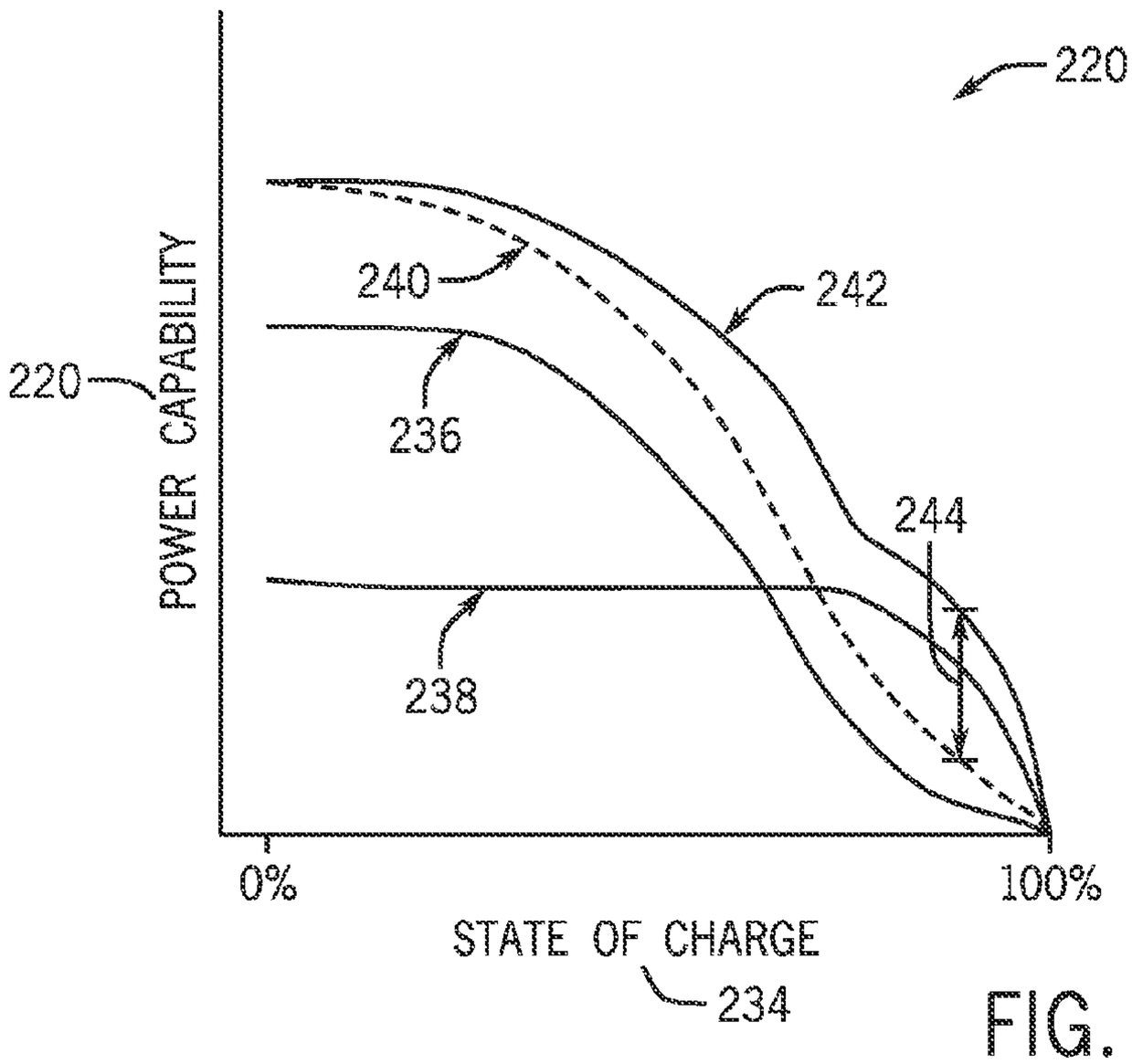

220
240
242
220
236
244
POWER CAPABILITY
238
0%
100%
STATE OF CHARGE
234

FIG. 20

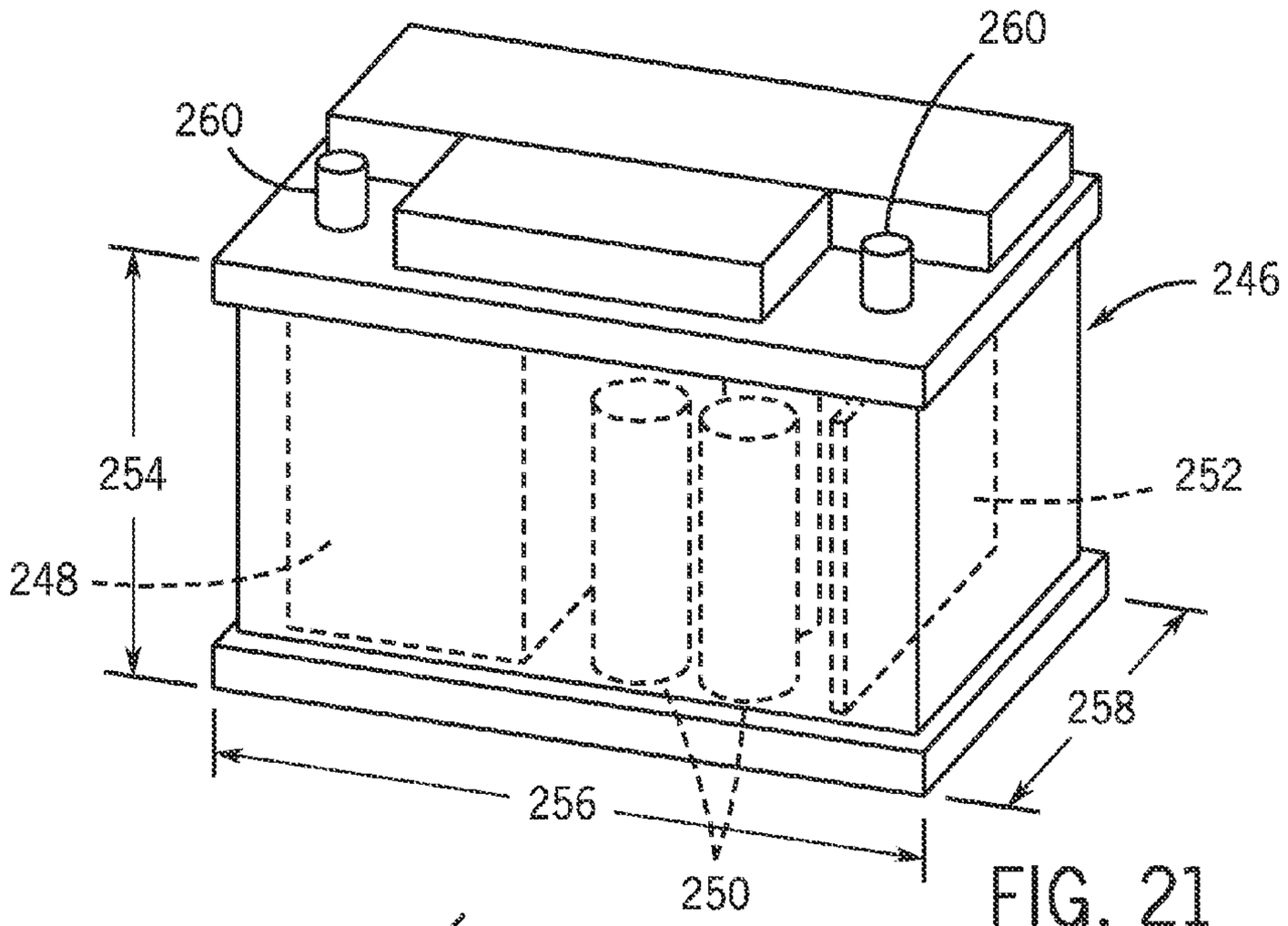

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260
246
254
252
248
258
256
250

FIG. 21

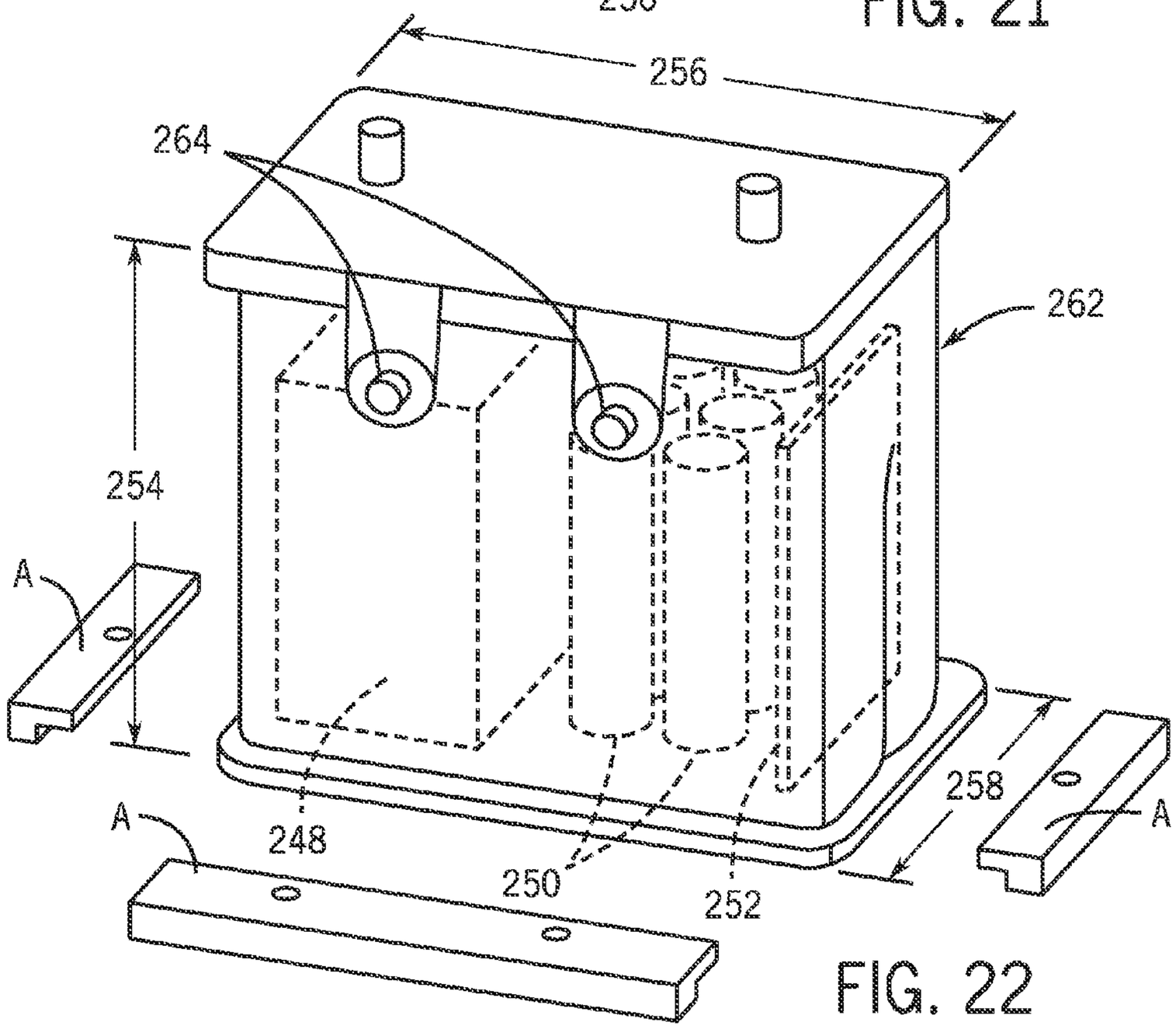

256
264
262
254
A
A
248
250
252
258
A

FIG. 22

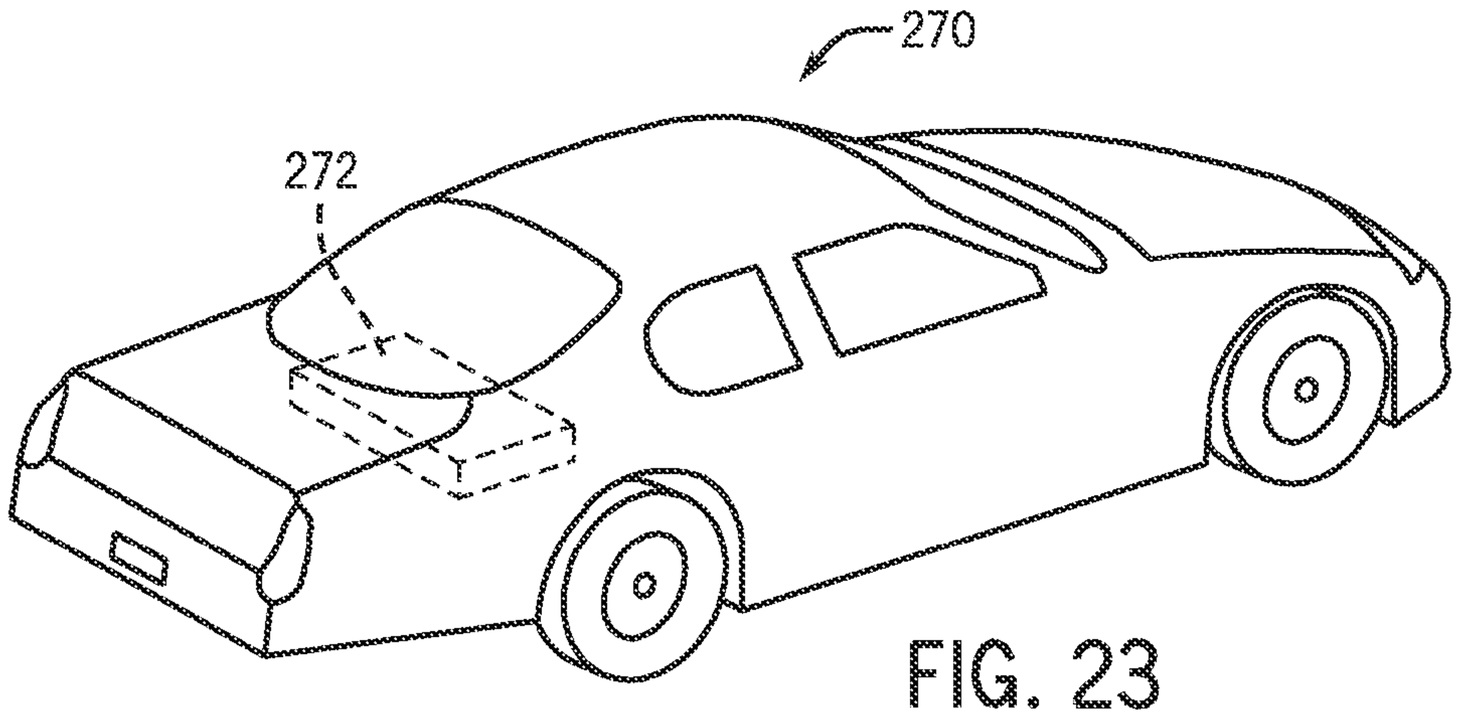


FIG. 23

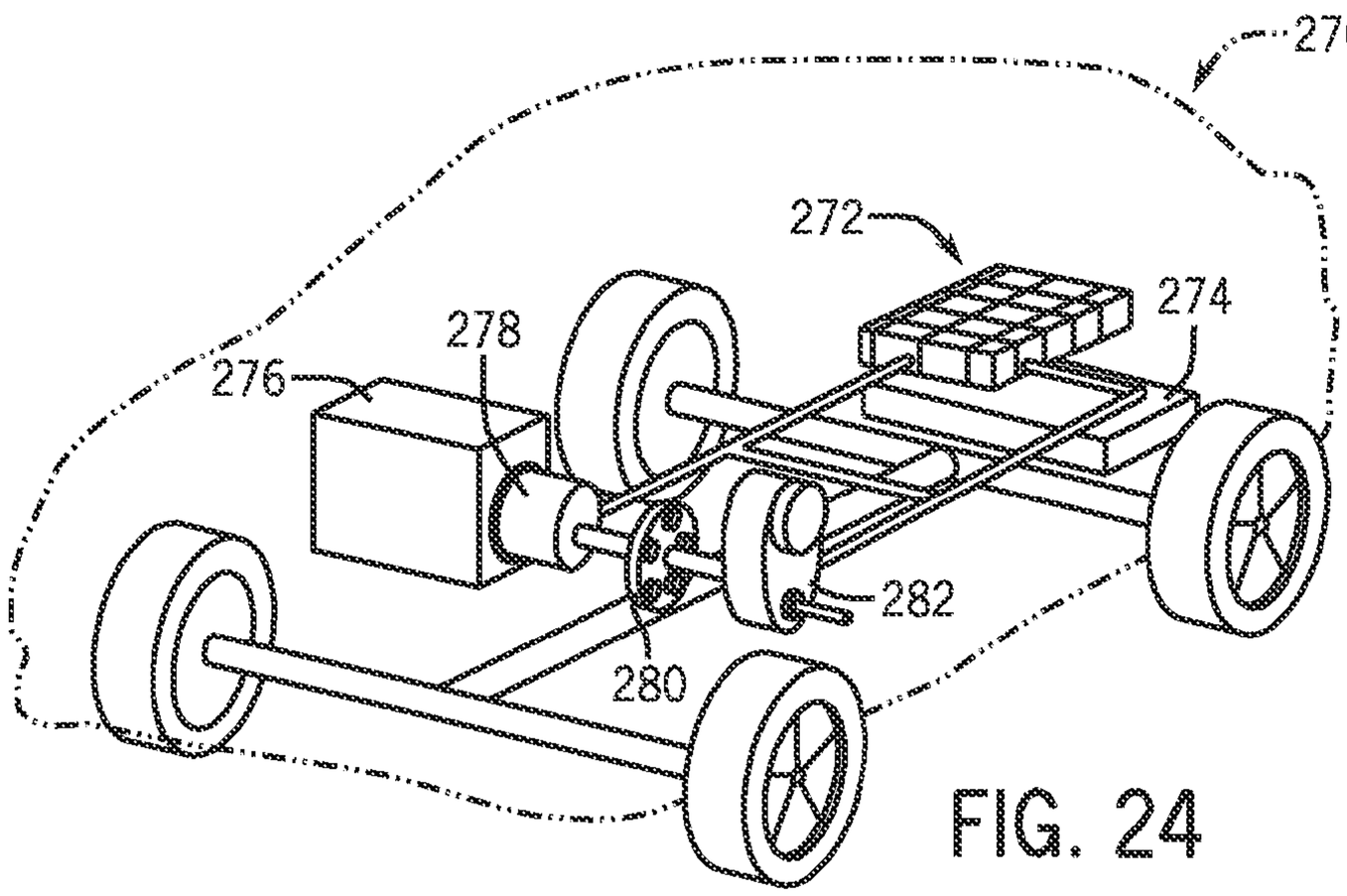


FIG. 24

ENERGY SOURCE SYSTEMS HAVING DEVICES WITH DIFFERENTIAL STATES OF CHARGE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Non-Provisional application of U.S. Provisional Patent Application No. 61/453,474, entitled "Combined Battery and Super Capacitor Systems for Vehicle Applications," filed Mar. 16, 2011, and U.S. Provisional Patent Application No. 61/508,621, entitled "System for Storage of Charge and Energy with an Integrated Controller," filed Jul. 16, 2011, and U.S. Provisional Patent Application No. 61/477,730, entitled "Multiple Battery System for Vehicle Applications," filed Apr. 21, 2011, and U.S. Provisional Patent Application No. 61/508,622, entitled "Differential State of Charge Battery for Improved Charging Capability," filed Jul. 16, 2011, which are herein incorporated by reference.

The present patent application is generally related to the following co-pending patent applications, which are hereby incorporated into the present application by reference: U.S. application Ser. No. 13/422,326, entitled "Systems and Methods for Controlling Multiple Storage Devices", filed by Brian C. Sisk et al. on even date herewith; U.S. application Ser. No. 13/422,421, entitled "Energy Source Devices and Systems Having a Battery and An Ultracapacitor", filed by Junwei Jiang et al. on even date herewith; U.S. application Ser. No. 13/422,514, entitled "Energy Source System Having Multiple Energy Storage Devices", filed by Thomas M. Watson et al. on even date herewith; and U.S. application Ser. No. 13/422,621, entitled "Systems and Methods for Overcharge Protection and Charge Balance in Combined Energy Source Systems", filed by Junwei Jiang et al. on even date herewith.

BACKGROUND

This section is intended to provide a background or context to the invention recited in the claims. The description herein may include concepts that could be pursued, but are not necessarily ones that have been previously conceived or pursued. Therefore, unless otherwise indicated herein, what is described in this section is not prior art to the description and claims in this application and is not admitted to be prior art by inclusion in this section.

It is generally known to provide typical Pb-acid batteries for starting, lighting, and ignition (SLI) applications in a vehicle. Such Pb-acid batteries usually have a capacity of about 70 Ah and a voltage of about 12V. The weight of such Pb-acid batteries is typically about 21 kg and the energy density is often about 40 Wh/kg. One performance requirement for such Pb-acid batteries for SLI applications is referred to as the "cold cranking current," which is about 700 Ah at (−)18° C. Such a high cold cranking current requirement is for the vehicle engine starting purpose, for delivery within a few seconds, especially under cold weather conditions. However, such known Pb-acid batteries, in order to meet the cold cranking current requirement, are sized such that they tend to occupy a relatively large amount of space, and add a significant amount of weight to the vehicle platform.

Another drawback with conventional battery systems is the issue of poor charge acceptance. That is, in certain instances, the battery may not be capable of handling the high charge current, which may have an undesirable impact

on the vehicle's energy regeneration capability. Accordingly, it would be desirable to provide one or more advanced energy source systems that are capable of efficiently meeting the cold cranking current requirements for engine starting while being packaged in a smaller and lighter device. Further, it would also be desirable to provide one or more advanced energy source systems that are adaptable for use with components associated with start-stop technology or components of the vehicle (e.g. to permit stopping of the vehicle engine during standstill periods and restart upon demand by the driver), or with components associated with mild-hybrid technology or components of the vehicle (e.g. to provide motor-driven boost or assist in accelerating a vehicle to a cruising speed), and electrical vehicle applications, and in a voltage range of approximately 10-400V, and more particularly within a range of approximately 10-100V.

SUMMARY

In one embodiment, a system includes a housing having a positive terminal and a negative terminal. A first energy storage device is disposed in the housing and adapted to operate at a first state of charge level. Additionally, a second energy storage device is disposed in the housing and adapted to operate at a second state of charge level. The second state of charge level is greater than the first state of charge level.

In another embodiment, an energy storage system includes a housing having a positive terminal and a negative terminal. A first energy storage device is disposed in the housing and has a first charging rate during charging of the energy storage system. A second energy storage device is also disposed in the housing and has a second charging rate during charging of the energy storage system. The first charging rate is substantially greater than the second charging rate. Further, a controller is coupled to the first energy storage device and the second energy storage device controls charging of the energy storage system during a regenerative braking event associated with operation of a vehicle such that the first energy storage device receives regenerative energy associated with the regenerative braking event at the first charging rate.

In another embodiment, a system includes a housing having a positive terminal and a negative terminal. A first energy storage device is disposed in the housing and adapted to accept charge at a first charge acceptance rate. A second energy storage device is also disposed in the housing and is adapted to accept charge at a second charge acceptance rate. The second charge acceptance rate is less than the first charge acceptance rate.

DRAWINGS

The disclosure will become more fully understood from the following detailed description, taken in conjunction with the accompanying figures, wherein like reference numerals refer to like elements, in which:

FIG. **1** illustrates an electrical supply system having a negative terminal and a positive terminal disposed on a housing that encloses an energy storage device and an ultracapacitor in accordance with an embodiment;

FIG. **2** is a schematic representation of a battery and ultracapacitor design for vehicle applications according to one embodiment of the systems described herein;

FIG. **3** illustrates an embodiment of a circuit that may be utilized to electrically couple an energy storage device and an ultracapacitor within a housing having two terminals in accordance with an embodiment;

FIG. **4** illustrates an embodiment of a circuit that may be utilized to electrically couple an energy storage device and an ultracapacitor utilizing at least one variable resistance device in accordance with an embodiment;

FIG. **5** illustrates an embodiment of a method that may be implemented by a controller to utilize sensed feedback to intelligently control operation of a multiple device system in accordance with an embodiment;

FIG. **6** illustrates an embodiment of a circuit that may be utilized to electrically couple an energy storage device, an ultracapacitor, and a DC/DC converter within a housing having two terminals in accordance with an embodiment;

FIG. **7** illustrates an embodiment of a safe start method that may be implemented by a controller to control a battery and an ultracapacitor in accordance with an embodiment;

FIG. **8** is a schematic representation of a battery and ultracapacitor design for vehicle applications according to a first embodiment of the systems described herein;

FIG. **9** is a schematic representation of a battery and ultracapacitor design for vehicle applications according to a second embodiment of the systems described herein;

FIG. **10** is a schematic representation of a battery and ultracapacitor design for vehicle applications according to a third embodiment of the systems described herein;

FIG. **11** is a schematic representation of a battery and ultracapacitor design for vehicle applications according to a fourth embodiment of the systems described herein;

FIG. **12** is a schematic representation of a battery and ultracapacitor design for vehicle applications according to a fifth embodiment of the systems described herein;

FIG. **13** is a schematic representation of a battery and ultracapacitor design for vehicle applications according to a sixth embodiment of the systems described herein;

FIG. **14** is a schematic representation of a battery and ultracapacitor design for vehicle applications according to a seventh embodiment of the systems described herein;

FIG. **15** is a schematic representation of a battery and ultracapacitor design for vehicle applications according to an eighth embodiment of the systems described herein;

FIG. **16** illustrates an energy source system including a differential state of charge (SOC) energy storage device having a housing that encloses a low SOC energy storage device and a high SOC energy storage device in a single enclosure in accordance with an embodiment;

FIG. **17** illustrates an embodiment of voltage versus state of charge (SOC) curves for energy storage devices having different states of charge in accordance with an embodiment;

FIG. **18** illustrates an embodiment of voltage versus state of charge (SOC) curves for energy storage devices having different states of charge in accordance with an embodiment;

FIG. **19** illustrates a power capability advantage that may be gained by combining a low state of charge (SOC) device and a high SOC device in a single package in accordance with an embodiment;

FIG. **20** illustrates a power capability advantage that may be gained by combining a low state of charge (SOC) device and a high SOC device in a single package in accordance with an embodiment;

FIG. **21** illustrates an embodiment of a standard battery enclosure that is internally configured to house one or more batteries or cells and one or more ultracapacitors;

FIG. **22** illustrates an embodiment of a battery enclosure having dimensions that conform and a unique shape that may conform to those of a desired battery that the new assembly and circuitry are intended to replace;

FIG. **23** is perspective view of an embodiment of a vehicle having a battery module or system for providing all or a portion of the motive power for the vehicle; and

FIG. **24** illustrates a cutaway schematic view of an embodiment of the vehicle of FIG. **23** provided in the form of a hybrid electric vehicle.

DETAILED DESCRIPTION

In accordance with presently disclosed embodiments, provided herein are advanced battery and ultracapacitor systems having overcharge protection and charge balancing capabilities. In some embodiments, the high power discharge capability of the ultracapacitors may be utilized to meet the cold cranking current requirements for a vehicle engine start, and a smaller and lighter battery may be utilized to provide the energy for other vehicle electrical applications. According to any of the illustrated embodiments, the vehicle applications may include one or more of internal combustion engines, hybrid, micro-hybrid, start-stop and electric vehicle applications, and may include voltage applications within the range of approximately 10V to approximately 400V, and more particularly, within a range of approximately 10V and approximately 100V. Although only a certain number of battery types have been described in the illustrated embodiments by way of example, any of a wide variety of other battery types and chemistries may be adapted for use with ultracapacitors for use in providing a smaller and/or lighter electrical power supply for a wide variety of vehicle applications. Accordingly, all such variations are intended to be within the scope of this disclosure.

One type of battery technology suitable for use with the systems described herein in Li-ion technology. The Li-ion battery technology provides a relatively high energy density up to about 200 Wh/kg, which is generally about five times that of the Pb-acid battery energy density. Thus, there are benefits for using Li-ion battery technology in some embodiments to replace the conventional Pb-acid battery for SLI applications in vehicles, such as (by way of example, and not limited to) elimination of Pb toxic compounds, lighter weight, and smaller space requirements. However, the cold cranking performance of Li-ion technology, by itself, is generally understood to limit the use of Li-ion technology in such applications. A typical Li-ion battery discharge rate at (−)18° C. is generally about a 2 C rate, where 2 C rate represents a discharge current of about 140 A for 70 Ah batteries, which is lower than the typical Pb-acid battery cold cranking performance (around 10 C rate).

Turning now to the drawings, FIG. **1** illustrates an electrical supply system **10** having a housing **12** with a negative terminal **14** that is connected to ground **16** and a positive terminal **18** that is capable of being coupled to an implementation-specific vehicle connection **20**, such as a switch, a starter motor, etc. As shown, an energy storage device **22** and an ultracapacitor **24** are provided within the housing **12**. That is, a single housing **12** having two terminals **14** and **18** encloses both the energy storage device **22** and the ultracapacitor **24**. The foregoing feature may enable the electrical supply system **10** to be dimensioned in such a way that enables the system **10** to be utilized to replace a variety of battery devices having standardized dimensions, for example, a standard 12V battery. As such, it should be noted that the housing **12** and the configuration of the terminals **14** and **18** may be susceptible to a variety of implementation-specific variations in size, shape, and placement, as discussed in more detail below. For example, in certain embodiments the system may be designed such that the housing or

enclosure is configured to permit simple and direct replacement of existing battery systems, such as conventional vehicular batteries. As such, the enclosure may conform to standard sizing and form factors, particularly relating to the length, width, and height of the enclosure, the placement of terminals, the configuration of the terminals, the placement and dimensions of features intended to hold the battery system in place, and so forth. Where desired, the actual enclosure may be somewhat smaller than such conventional form factors, and adapters, shims and similar structures may be used to allow for such replacement. Such adapters and structures may also allow for the use of enclosures of irregular or non-standard shapes. In either case, there may be need for little or no change in the supporting and interfacing structures of the vehicle or other application in which the system is placed as compared to current structures.

It should be noted that, as will be appreciated by those skilled in the art, distinctions exist between "charge" and "energy", both physically and in terms of unitary analysis. In general, charge will be stored and energy converted during use. However, in the present context, the two terms will often be used somewhat interchangeably. Thus, at times reference is made to "charge storage" or to "the flow of charge", or to similar handling of "energy". This use should not be interpreted as technically inaccurate or limiting insomuch as the batteries, ultracapacitors, and other devices and components may be said, in common parlance, to function as either energy storage devices or charge storage devices, and sometimes as either or both.

Further, as shown in the illustrated embodiment, the housing **12** also encloses a controller **26** that is coupled to the energy storage device **22** and the ultracapacitor **24** and may control operation of the multiple device system. It should be noted that the controller **26** shown in FIG. **1** may be any controller that is suitable for use with a multiple device system. However, in some presently contemplated embodiments, the energy storage device **22** and the ultracapacitor **24** may be controlled by a multiple device controller such as the controller described in the co-pending application entitled "SYSTEMS AND METHODS FOR CONTROLLING MULTIPLE STORAGE DEVICES," which is hereby incorporated by reference, as previously mentioned.

Further, it should be noted that the energy storage device **22** and the ultracapacitor **24** in FIG. **1** are merely illustrative, and each device may include one or more devices in other embodiments. For example, referring generally to the embodiment illustrated in FIG. **2**, a combination of Li-ion technology with an ultracapacitor pack may provide an improved vehicle electrical power system, since the high power ultracapacitor can quickly discharge with high power to start the vehicle engine (e.g., within approximately 2 or 3 seconds). More specifically, FIG. **2** illustrates one embodiment of the design of the combination of a Li-ion battery **28** having four cells **30**, **32**, **34**, and **36** (each with a capacity of approximately 15 Ah) and a bank **38** of ultracapacitors **40**, **42**, **44**, **46**, **48**, and **50** (each with a capacity of about 2000 Farads and 2.7 VDC). In one embodiment, the average voltage of each Li-ion battery cell (LiFePO4/graphite) is about 3.3V, and thus, the four cell pack in series provides a voltage of about 13.2V. The six ultracapacitors **40**, **42**, **44**, **46**, **48**, and **50** in series provide an average voltage of about 12V.

Further, during cold cranking current requirements, the ultracapacitor pack **38** can supply a maximum current of about 2,000 Amps within 2 seconds at cold temperatures around (−)18° C., which is generally understood to be sufficient to start a vehicle engine. Further, the total weight of such a four cell Li-ion battery and six ultracapacitor pack is about seven 7 kg, compared to a weight of about 21 kg for a Pb-acid battery with a capacity of about 70 Ah for vehicle starting, lighting, and ignition (SLI) applications. The maximum power for such a Li-ion and ultracapacitor system reaches to about 46 kW, compared to about 5.6 kW for the Pb-acid battery pack (70 Ah) at low temperatures of about (−)18° C.

FIGS. **3** and **4** illustrate additional embodiments of circuits **52** and **54** that may be utilized to electrically couple an embodiment of the energy storage device **22** and an embodiment of the ultracapacitor **24** for packaging in the housing **12** having two terminals **14** and **18**. Specifically, in the illustrated embodiments, a battery **56** and a capacitor **58**, which may be an ultracapacitor in certain embodiments, are coupled to a current sensor **60**. In the embodiment of FIG. **3**, the battery **56** is electrically coupled to the positive terminal **18** via a first switch **62**, and the capacitor **58** is electrically coupled to the positive terminal **18** via a second switch **64**. However, it should be noted that the switches **62** and **64** illustrated in FIG. **3** may, in other embodiments, be variable resistance devices capable of feathering in and out the associated device, for example, as dictated by the controller **26**. For instance, in the embodiment of FIG. **4**, the second switch **64** is a field-effect transistor (FET) **66** capable of being controlled to connect and disconnect the capacitor **58** to a load present at the positive terminal **18** in a variable manner. Additionally, it should be noted that in other embodiments, the first switch **62** may also be a variable resistance device, such as a FET.

During operation, the current sensor **60** senses the current draw present at the load, thus enabling the controller **26** to determine, based on the sensed level, the nature of the load that is present. For example, the current sensor **60** may sense a level that corresponds to an accessory drain or alternatively, the current sensor **60** may sense a level that corresponds to a power draw. The controller **26** may then utilize the sensed current level to determine which of the battery **56** and the capacitor **58** should be activated, for example, via closing of the switches **62** and **64**. For example, if an accessory drain from a vehicle is detected at the load, the switch **62** may be closed, thus enabling the battery **56** to meet the accessory demand. For further example, if a power draw, such as a draw associated with starting of an internal combustion engine, is detected, the switch **64** may be closed to enable the capacitor **58** to meet the power draw. Still further, in some embodiments, the controller may control the FET **66** and a FET coupled to the battery **56** such that the load is met by a combination of power delivered from the devices **56** and **58**. Accordingly, presently disclosed embodiments may provide for sensing a parameter of the load and intelligently controlling the devices **56** and **58** to meet the demand present at the load.

FIG. **5** illustrates an embodiment of a method **68** that may be implemented by, for example, the controller **26**, to utilize the sensed feedback to intelligently control operation of the multiple device system. Once the operation is started (block **70**), the controller **26** receives an initial value for the current draw level (block **72**), for example, from the current sensor **60**, and then receives a present value of the current draw at a later time point (block **74**). In this embodiment, the method **68** proceeds with an inquiry as to whether the rate of change of the current draw with respect to time is greater than or equal to a preset threshold (block **76**). If the rate of change of the sensed current meets or exceeds the given threshold, the controller **26** activates the capacitor **58** to meet the demand (block **78**). For example, the controller may utilize

switch **64** to couple the capacitor **58** to the load present at the positive terminal **18**. However, if the rate of change of the sensed current is below the preset threshold, the battery **56** is activated to meet the demand at the load (block **80**).

In this way, the rate of change of sensed current over time may be utilized to determine which of the devices **56** and **58** are utilized to meet the demand of the load. It should be noted that although the sensor in the illustrated embodiment is a current sensor, in other embodiments, any suitable sensor or combination of sensors capable of sensing a load parameter may be utilized. Additionally, any suitable indicator, not limited to the rate of change of current with respect to time, may be utilized to determine which device is activated to meet the demand at the load. Still further, in certain embodiments, a variety of thresholds or inquiries may be utilized to determine which portion of the load should be met by each device. That is, in certain embodiments, the controller may utilize additional logic to determine an appropriate shared distribution of the load between the devices.

FIG. **6** illustrates an additional embodiment of a circuit **82** that may be utilized to electrically couple the battery **56** and the capacitor **58** to the load present at the positive terminal **18**. In this embodiment, as before, the switches **62** and **64** couple the battery **56** and the capacitor **58**, respectively, to the positive terminal **18**. However, as shown, the circuit **82** includes a direct current to direct current (DC/DC) converter that electrically couples the battery **56** and the capacitor **58**. Further, a sensing system **85** includes a battery voltage sensor **86**, a capacitor voltage sensor **88**, and a net voltage sensor **90** capable of measuring the voltage of the battery, the voltage of the capacitor, and the net voltage, respectively, throughout operation of the circuit **82**.

During operation of the circuit **82**, the sensing system **85** may be utilized to measure voltage levels at a variety of locations in the circuit **82**, thus enabling the controller **26** to acquire information regarding both load requirements as well as the quantity of energy each of the devices **56** and **58** is capable of providing. Therefore, based on the information received from the sensing system **85**, the controller **26** may control the switches **62** and **64** and the DC/DC converter **84** to meet the demand at the load in accordance with energy available from each of the devices **56** and **58** at any given operational time point. Further, it should be noted that, as before, the switches **62** and **64** may be variable devices, such as FETs, that enable the controller to feather in and out each of the devices as appropriate.

In one embodiment, the circuit **82** of FIG. **6** may be packaged, for example, within housing **12**, with the controller **26** and utilized in place of a traditional vehicle battery. In such an embodiment, the circuit **82**, operated under control of the controller **26**, may be utilized to reduce or eliminate the likelihood that the vehicle in which the device **10** is placed is unable to start when the voltage of the battery **56** is drained below a level sufficient to start, for example, the internal combustion engine of the vehicle. Here again, it should be noted that, as discussed in more detail below, the housing **12** and the configuration of the terminals **14** and **18** may be dimensioned and configured for the vehicle in which the device **10** is intended to be utilized.

FIG. **7** illustrates an embodiment of a method **92** that may be implemented by the controller **26** to ensure that a vehicle with which the circuit **82** is associated is started if possible given the energy available in the devices **56** and **58**. Once the operation is started (block **94**), an operator demand to start the vehicle is detected (block **96**). For example, the operator may insert and turn a key in a console of the vehicle, press a button to start the vehicle, and so forth, depending on the specific vehicle type. In some embodiments, the battery **56** may be designated as the primary energy source that is to be utilized for routine vehicle starting events. In such embodiments, at certain times, the voltage of the battery may be too low to support an engine start event, and the controller **26** receives an input indicating that the available voltage from the battery is insufficient to meet the operator demand to start the vehicle (block **98**).

In such instances, presently disclosed embodiments provide for a reduced or prevented likelihood that battery drainage will prohibit the vehicle from being started. More specifically, the method **92** includes the step of controlling the DC/DC converter **84** to utilize the available voltage in the battery **56** to charge the capacitor **58** (block **100**). That is, although the voltage in the battery **56** may be insufficient to start the vehicle, the available voltage may be sufficient to charge the capacitor **58**. Once the vehicle fails to start upon the operator's first request, the operator may again attempt to start the vehicle, and the controller **26** detects this demand (block **102**). Since the capacitor **58** was charged during the time lapse between the first start attempt and the second start attempt, the capacitor **58** may be utilized to start the vehicle (block **104**), thus fulfilling the operator request. In this way, the circuit **82** may be controlled to reduce or prevent the likelihood that the vehicle will not be able to start when the battery voltage is low, thus offering advantages over traditional systems that may utilize a battery in place of the multiple device system **10**.

FIGS. **8-15** illustrate additional embodiments of circuits including various combinations of batteries, ultracapacitors, overcharge protection circuits, and charge balancing circuits. Specifically, FIG. **8** illustrates an embodiment of a combined battery and ultracapacitor system **106** for vehicle applications with recharge capability. The system **106** as shown in FIG. **8** includes a battery **108** having a number of cells (or battery units) C**1**, C**2**, . . . CX that are connected in series and to terminals T**3** (**110**) and T**4** (**112**), which are connected to the alternator of the vehicle's electrical system for maintaining the charge on the battery cells **108** (and providing a power source to other electrical loads of the vehicle). An ultracapacitor pack **114** is shown connected in parallel with the battery **108** and has individual ultracapacitors S**1**, S**2**, . . . SY connected in series with one another and to terminals T**1** (**116**) and T**2** (**118**), which are connected to the engine-starting portion of the vehicle's electrical system for providing relatively short and high current for starting the vehicle. The number of ultracapacitors and the capacity of the ultracapacitors are selected so that the total voltage of the ultracapacitors **114** substantially matches the total voltage of the series of cells in the battery **108**. The system **106** also includes a management and control system **120** that permits the battery **108** to quickly recharge the ultracapacitors **114** following discharge (e.g. engine starts).

According to the illustrated embodiment, the management and control system **120** includes first management and control circuitry **122** that is associated with the ultracapacitors **114**, as well as second management and control circuitry **124** that is associated with the battery **108**. During operation, the management and control system **120** operates to provide overcharge protection and charge balance for the ultracapacitors **114**. As such, it should be noted that the first control circuitry **122** and the second control circuitry **124** may communicate with one another, for example, via a wired or wireless connection, to coordinate operation of the battery **108** and the ultracapacitors **114**. Further, in certain embodiments, the management and control system **120** monitors,

controls, and balances the battery **108** and the ultracapacitors **114**. As such, during operation, the functions of the management and control system **120** may include, but are not limited to monitoring parameters of the battery and ultracapacitors (e.g., voltage, temperature, state of charge/discharge, state of health, current, etc.), computing desired parameters (e.g., maximum charge/discharge current, total energy delivery, total operating time, etc.), communicating with system components (e.g., via CAN bus, wireless communication, etc.), providing protection capabilities (e.g., over-current, over-charge/discharge voltage, over/under temperature, etc.), and balancing to enable the function of energy storage system.

More specifically, during operation, the control circuitry **122** and **124** controls the flow of energy between the battery **108** and the ultracapacitors **114** to permit current flow only in the direction from the battery **108** to the ultracapacitors **114**. Further, the first control circuitry **122** is coupled to each ultracapacitor to provide overcharge protection and balancing of the charge among the ultracapacitors as current flows from the battery **108** to the ultracapacitors **114**. For example, in some embodiments, the control circuitry **122** may control the current flow such that as the flow from the battery **108** reaches each ultracapacitor (from S**1** to Sy), current is directed first to S**1**, then to S**2** and so on, until the current reaches Sy. In this way, when each ultracapacitor reaches its required voltage level, the current from the battery **108** will bypass that ultracapacitor to balance with the other ultracapacitors in the pack **114**. According to other embodiments, other components or devices may be used to balance the charging of the ultracapacitors; all such variations are intended to be within the scope of this disclosure.

FIG. **9** illustrates a combined 12V Pb-acid battery and ultracapacitor system **128** for vehicle applications with recharge capability, according to a presently disclosed embodiment. The system **128**, as shown in FIG. **9** includes a battery **130** having a number of cells (or battery units) shown as six cells C**1**, C**2**, C**3**, C**4**, C**5** and C**6** that are connected in series with one another and to terminals T**3** (**110**) and T**4** (**112**), which are connected to the alternator of the vehicle's electrical system for maintaining the charge on the battery cells (and providing a power source to other electrical loads of the vehicle). An ultracapacitor pack **132** is shown connected in parallel with the battery **130** and has six individual ultracapacitors S**1**, S**2**, S**3**, S**4**, S**5** and S**6** connected in series with one another and to terminals T**1** (**116**) and T**2** (**118**), which are connected to the engine-starting portion of the vehicle's electrical system for providing relatively short and high current for starting the vehicle. The number of ultracapacitors and the capacity of the ultracapacitors are selected so that the total voltage of the ultracapacitors **132** substantially matches the total voltage of the series of cells in the battery **130**. According to the embodiment of FIG. **9**, each of the six Pb-acid cells has a voltage of approximately 2V, so that the total voltage of the battery is about 12V. Also, each of the six ultracapacitors has an average voltage of about 1.9V (but may be within the range of about 1V-2.8V). Accordingly, six ultracapacitors are selected so that the total voltage approximately matches the voltage of the Pb-acid battery.

The system of FIG. **9** also includes the management and control system **120** that permits the Pb-acid battery **130** to quickly recharge the six ultracapacitors **132** following discharge (e.g. engine starts). As before, in the illustrated embodiment, the management and control system **120** includes the first management and control circuitry **122** and the second management and control circuitry **124**. During operation, the management and control system **120** operates to provide overcharge protection and charge balance for the ultracapacitors **132**. More specifically, during operation, the control circuitry **122** and **124** controls the flow of energy between the Pb-acid battery **130** and the ultracapacitors **132** to permit current flow only in the direction from the Pb-acid battery **130** to the ultracapacitors **132**.

Further, the first control circuitry **122** is coupled to each ultracapacitor to provide overcharge protection and balancing of the charge among the ultracapacitors as current flows from the Pb-acid battery **130** to the ultracapacitors **132**. For example, in some embodiments, the control circuitry **122** may control the current flow such that as the flow from the Pb-acid battery **130** reaches each ultracapacitor (from S**1** to S**6**), current is directed first to S**1**, then to S**2** and so on, until the current reaches S**6**. In this way, when each ultracapacitor reaches its required voltage level, the current from the Pb-acid battery **130** will bypass that ultracapacitor to balance with the other ultracapacitors in the pack **132**. According to other embodiments, other components or devices may be used to balance the charging of the ultracapacitors; all such variations are intended to be within the scope of this disclosure.

Referring to FIG. **10**, a combined 13V Li-ion (LiFePO4 cathode/carbon anode) battery and ultracapacitor system **150** for vehicle applications with recharge capability is shown according to a presently disclosed embodiment. The system **150**, as shown in FIG. **10**, includes a battery **152** having a number of cells (or battery units) shown as four cells C**1**-C**4** that are connected in series with one another and to terminals T**3** (**110**) and T**4** (**112**), which are connected to the alternator of the vehicle's electrical system for maintaining the charge on the battery cells **152** (and providing a power source to other electrical loads of the vehicle). A ultracapacitor pack **132** is shown connected in parallel with the battery **152** and has six individual ultracapacitors S**1**, S**2**, S**3**, S**4**, S**5** and S**6** connected in series with one another and to terminals T**1** (**116**) and T**2** (**118**), which are connected to the engine-starting portion of the vehicle's electrical system for providing relatively short and high current for starting the vehicle. As before, the number of ultracapacitors and the capacity of the ultracapacitors are selected so that the total voltage of the ultracapacitors substantially matches the total voltage of the series of cells in the battery. According to the embodiment of FIG. **10**, each of the four Li-ion cells has a voltage of approximately 3.3V, so that the total voltage of the battery is about 13.2V. Also, each of the six ultracapacitors has an average voltage of about 1.9V (but may be within the range of about 1V-2.8V). Accordingly, six ultracapacitors are selected so that the total voltage approximately matches the voltage of the Li-ion battery.

The system of FIG. **10** also includes the management and control system **120** that permits the Li-ion battery to quickly recharge the six ultracapacitors following discharge (e.g. engine starts). In the illustrated embodiment, the management and control system **120** includes the first management and control circuitry **122** and the second management and control circuitry **124** that cooperatively operate to provide overcharge protection and charge balance for the ultracapacitors **132**. More specifically, during operation, the control circuitry **122** and **124** controls the flow of energy between the Li-ion battery **152** and the ultracapacitors **132** to permit current flow only in the direction from the Li-ion battery **152** to the ultracapacitors **132**.

Further, the first control circuitry **122** is coupled to each ultracapacitor to provide overcharge protection and balancing of the charge among the ultracapacitors as current flows

from the Li-ion battery **152** to the ultracapacitors **132**. For example, in some embodiments, the control circuitry **122** may control the current flow such that as the flow from the Li-ion battery **152** reaches each ultracapacitor (from S**1** to S**6**), current is directed first to S**1**, then to S**2** and so on, until the current reaches S**6**. In this way, when each ultracapacitor reaches its required voltage level, the current from the Li-ion battery **152** will bypass that ultracapacitor to balance with the other ultracapacitors in the pack **132**. According to other embodiments, other components or devices may be used to balance the charging of the ultracapacitors; all such variations are intended to be within the scope of this disclosure.

Referring to FIG. **11**, a combined 13V Li-ion ($LiMn_2O_4$ cathode/$Li_4Ti_5O_{12}$ anode) battery and ultracapacitor system **154** for vehicle applications with recharge capability is shown according to an exemplary embodiment. The system as shown in FIG. **11** includes a battery **156** having a number of cells (or battery units) shown as six cells C**1**-C**6** that are connected in series with one another and to terminals T**3** (**110**) and T**4** (**112**), which are connected to the alternator of the vehicle's electrical system for maintaining the charge on the battery cells (and providing a power source to other electrical loads of the vehicle). The ultracapacitor pack **132** is shown connected in parallel with the battery **156** and has six individual ultracapacitors S**1**, S**2**, S**3**, S**4**, S**5** and S**6** connected in series with one another and to terminals T**1** (**116**) and T**2** (**118**), which are connected to the engine-starting portion of the vehicle's electrical system for providing relatively short and high current for starting the vehicle. The number of ultracapacitors and the capacity of the ultracapacitors are selected so that the total voltage of the ultracapacitors substantially matches the total voltage of the series of cells in the battery. According to the embodiment of FIG. **11**, each of the six Li-ion cells (with a $LiMn_2O_4$ cathode and a $Li_4Ti_5O_{12}$ anode) has a voltage of approximately 2.2V, so that the total voltage of the battery **156** is about 13.2V. Also, each of the six ultracapacitors has an average voltage of about 1.9V (but may be within the range of about 1V-2.8V). Accordingly, six ultracapacitors are selected so that the total voltage approximately matches the voltage of the Li-ion battery.

The system of FIG. **11** also includes the management and control system **120** that permits the Li-ion battery **156** to quickly recharge the six ultracapacitors **132** following discharge (e.g. engine starts). In the illustrated embodiment, the management and control system **120** includes the first management and control circuitry **122** and the second management and control circuitry **124** that cooperatively operate to provide overcharge protection and charge balance for the ultracapacitors **132**. More specifically, during operation, the control circuitry **122** and **124** controls the flow of energy between the Li-ion battery **156** and the ultracapacitors **132** to permit current flow only in the direction from the Li-ion battery **156** to the ultracapacitors **132**.

Further, the first control circuitry **122** is coupled to each ultracapacitor to provide overcharge protection and balancing of the charge among the ultracapacitors as current flows from the Li-ion battery **156** to the ultracapacitors **132**. For example, in some embodiments, the control circuitry **122** may control the current flow such that as the flow from the Li-ion battery **156** reaches each ultracapacitor (from S**1** to S**6**), current is directed first to S**1**, then to S**2** and so on, until the current reaches S**6**. In this way, when each ultracapacitor reaches its required voltage level, the current from the Li-ion battery **156** will bypass that ultracapacitor to balance with the other ultracapacitors in the pack **132**. According to other embodiments, other components or devices may be used to balance the charging of the ultracapacitors; all such variations are intended to be within the scope of this disclosure.

Referring to FIG. **12**, a combined 12V Li-ion ($LiMn_{3/2}Ni_{1/2}O_4$ cathode/$Li_4Ti_5O_{12}$ anode) battery and ultracapacitor system **158** for vehicle applications with recharge capability is shown according to a presently disclosed embodiment. The system **158** as shown in FIG. **12** includes a battery **160** having a number of cells (or battery units) shown as four cells C**1**-C**4** that are connected in series with one another and to terminals T**3** (**110**) and T**4** (**112**), which are connected to the alternator of the vehicle's electrical system for maintaining the charge on the battery cells (and providing a power source to other electrical loads of the vehicle). The ultracapacitor pack **132** is shown connected in parallel with the battery **160** and has six individual ultracapacitors S**1**, S**2**, S**3**, S**4**, S**5** and S**6** connected in series with one another and to terminals T**1** (**116**) and T**2** (**118**), which are connected to the engine-starting portion of the vehicle's electrical system for providing relatively short and high current for starting the vehicle. The number of ultracapacitors and the capacity of the ultracapacitors are selected so that the total voltage of the ultracapacitors substantially matches the total voltage of the series of cells in the battery. According to the embodiment of FIG. **12**, each of the four Li-ion cells (with a $LiMn_{3/2}Ni_{1/2}O_4$ cathode and a $Li_4Ti_5O_{12}$ anode) has a voltage of approximately 3V, so that the total voltage of the battery is about 12V. Also, each of the six ultracapacitors has an average voltage of about 1.9V (but may be within the range of about 1V-2.8V). Accordingly, six ultracapacitors are selected so that the total voltage approximately matches the voltage of the Li-ion battery.

The system of FIG. **12** also includes the management and control system **120** that permits the Li-ion battery **160** to quickly recharge the six ultracapacitors following discharge (e.g. engine starts). In the illustrated embodiment, the management and control system **120** includes the first management and control circuitry **122** and the second management and control circuitry **124** that cooperatively operate to provide overcharge protection and charge balance for the ultracapacitors **132**. More specifically, during operation, the control circuitry **122** and **124** controls the flow of energy between the Li-ion battery **160** and the ultracapacitors **132** to permit current flow only in the direction from the Li-ion battery **160** to the ultracapacitors **132**.

Further, the first control circuitry **122** is coupled to each ultracapacitor to provide overcharge protection and balancing of the charge among the ultracapacitors as current flows from the Li-ion battery **160** to the ultracapacitors **132**. For example, in some embodiments, the control circuitry **122** may control the current flow such that as the flow from the Li-ion battery **160** reaches each ultracapacitor (from S**1** to S**6**), current is directed first to S**1**, then to S**2** and so on, until the current reaches S**6**. In this way, when each ultracapacitor reaches its required voltage level, the current from the Li-ion battery **160** will bypass that ultracapacitor to balance with the other ultracapacitors in the pack **132**. According to other embodiments, other components or devices may be used to balance the charging of the ultracapacitors; all such variations are intended to be within the scope of this disclosure.

Referring to FIG. **13**, a combined 24V Pb-acid battery and ultracapacitor system **162** for vehicle applications with recharge capability is shown according to an exemplary embodiment. The system as shown in FIG. **13** includes a battery **164** having a number of cells (or battery units) shown as twelve cells C**1**-C**12** that are connected in series with one another and to terminals T**3** (**110**) and T**4** (**112**), which are connected to the alternator of the vehicle's electrical system

for maintaining the charge on the battery cells (and providing a power source to other electrical loads of the vehicle). An ultracapacitor pack **166** is shown connected in parallel with the battery and has twelve individual ultracapacitors S**1**-S**12** connected in series with one another and to terminals T**1** (**116**) and T**2** (**118**), which are connected to the engine-starting portion of the vehicle's electrical system for providing relatively short and high current for starting the vehicle. The number of ultracapacitors and the capacity of the ultracapacitors are selected so that the total voltage of the ultracapacitors substantially matches the total voltage of the series of cells in the battery. According to the embodiment of FIG. **13**, each of the twelve Pb-acid cells has a voltage of approximately 2V, so that the total voltage of the battery is about 24V. Also, each of the twelve ultracapacitors has an average voltage of about 1.9V (but may be within the range of about 1V-2.8V). Accordingly, twelve ultracapacitors are selected so that the total voltage approximately matches the voltage of the Pb-acid battery **164**.

The system of FIG. **13** also includes the management and control system **120** that permits the Pb-acid battery **164** to quickly recharge the twelve ultracapacitors following discharge (e.g. engine starts). As before, in the illustrated embodiment, the management and control system **120** includes the first management and control circuitry **122** and the second management and control circuitry **124**. During operation, the management and control system **120** operates to provide overcharge protection and charge balance for the ultracapacitors **132**. More specifically, during operation, the control circuitry **122** and **124** controls the flow of energy between the Pb-acid battery **164** and the ultracapacitors **166** to permit current flow only in the direction from the Pb-acid battery **164** to the ultracapacitors **166**.

Further, the first control circuitry **122** is coupled to each ultracapacitor to provide overcharge protection and balancing of the charge among the ultracapacitors as current flows from the Pb-acid battery **164** to the ultracapacitors **166**. For example, in some embodiments, the control circuitry **122** may control the current flow such that as the flow from the Pb-acid battery **164** reaches each ultracapacitor (from S**1** to S**12**), current is directed first to S**1**, then to S**2** and so on, until the current reaches S**12**. In this way, when each ultracapacitor reaches its required voltage level, the current from the Pb-acid battery **164** will bypass that ultracapacitor to balance with the other ultracapacitors in the pack **166**. According to other embodiments, other components or devices may be used to balance the charging of the ultracapacitors; all such variations are intended to be within the scope of this disclosure.

Referring to FIG. **14**, a combined 26V Li-ion ($LiFePO_4$/graphite) battery and ultracapacitor system **170** for vehicle applications with recharge capability is shown according to a presently disclosed embodiment. The system **170** as shown in FIG. **14** includes a battery **172** having a number of cells (or battery units) shown as eight cells C**1**-C**8** that are connected in series with one another and to terminals T**3** (**110**) and T**4** (**112**), which are connected to the alternator of the vehicle's electrical system for maintaining the charge on the battery cells (and providing a power source to other electrical loads of the vehicle). The ultracapacitor pack **166** is shown connected in parallel with the battery **172** and has twelve individual ultracapacitors S**1**-S**12** connected in series with one another and to terminals T**1** (**116**) and T**2** (**118**), which are connected to the engine-starting portion of the vehicle's electrical system for providing relatively short and high current for starting the vehicle. The number of ultracapacitors and the capacity of the ultracapacitors are selected so that the total voltage of the ultracapacitors substantially matches the total voltage of the series of cells in the battery. According to the embodiment of FIG. **14**, each of the eight Li-ion cells has a voltage of approximately 3.2V, so that the total voltage of the battery **172** is about 26V. Also, each of the twelve ultracapacitors has an average voltage of about 1.9V (but may be within the range of about 1V-2.8V). Accordingly, twelve ultracapacitors are selected so that the total voltage approximately matches the voltage of the Li-ion battery.

The system of FIG. **14** also includes the management and control system **120** that permits the Li-ion battery **172** to quickly recharge the twelve ultracapacitors **166** following discharge (e.g. engine starts). As before, in the illustrated embodiment, the management and control system **120** includes the first management and control circuitry **122** and the second management and control circuitry **124**. During operation, the management and control system **120** operates to provide overcharge protection and charge balance for the ultracapacitors **166**. More specifically, during operation, the control circuitry **122** and **124** controls the flow of energy between the Li-ion battery **172** and the ultracapacitors **166** to permit current flow only in the direction from the Li-ion battery **172** to the ultracapacitors **166**.

Further, the first control circuitry **122** is coupled to each ultracapacitor to provide overcharge protection and balancing of the charge among the ultracapacitors as current flows from the Li-ion battery **172** to the ultracapacitors **166**. For example, in some embodiments, the control circuitry **122** may control the current flow such that as the flow from the Li-ion battery **172** reaches each ultracapacitor (from S**1** to S**12**), current is directed first to S**1**, then to S**2** and so on, until the current reaches S**12**. In this way, when each ultracapacitor reaches its required voltage level, the current from the Li-ion battery **172** will bypass that ultracapacitor to balance with the other ultracapacitors in the pack **166**. According to other embodiments, other components or devices may be used to balance the charging of the ultracapacitors; all such variations are intended to be within the scope of this disclosure.

Referring to FIG. **15**, a combined 48V battery and ultracapacitor system **174** for vehicle applications with recharge capability is shown according to a presently disclosed embodiment. The system **174** as shown in FIG. **15** includes a battery **176** having a number of cells (or battery units) shown as cells C**1**-CY that are connected in series with one another and to terminals T**3** (**110**) and T**4** (**112**), which are connected to the alternator of the vehicle's electrical system for maintaining the charge on the battery cells (and providing a power source to other electrical loads of the vehicle). An ultracapacitor pack **178** is shown connected in parallel with the battery **176** and has twelve individual ultracapacitors S**1**-SX connected in series with one another and to terminals T**1** (**116**) and T**2** (**118**), which are connected to the engine-starting portion of the vehicle's electrical system for providing relatively short and high current for starting the vehicle.

In one embodiment, the battery **176** may be a Pb-acid battery including cells C**1**-C**24**, and the ultracapacitor pack **178** may include between approximately 16 and approximately 30 ultracapacitors. In another embodiment, the battery **176** may be a Li-ion battery with $LiFePO_4$ contained positive material including cells C**1**-C**16**, and the ultracapacitor pack **178** may include between approximately 16 and approximately 30 ultracapacitors. Further, in another embodiment, the battery **176** may be a Li-ion battery with $LiMn_2O_4$ contained positive material including cells

C1-C13, and the ultracapacitor pack **178** may include between approximately 16 and approximately 30 ultracapacitors. Still further, in another embodiment, the battery **176** may be a Li-ion battery with $LiFePO_4$ contained positive material including cells C1-C16, and the ultracapacitor pack **178** may include between approximately 12 and approximately 24 ultracapacitors, and the ultracapacitors may be hybrid ultracapacitors with Li intercalation electrodes including a graphite contained negative electrode.

The system of FIG. **15** also includes the management and control system **120** to permit current flow only in the direction from the battery **176** to the ultracapacitors **178**. As before, in the illustrated embodiment, the management and control system **120** includes the first management and control circuitry **122** and the second management and control circuitry **124**. During operation, the management and control system **120** operates to provide overcharge protection and charge balance for the ultracapacitors **178**, as described in detail above with respect to FIGS. **8-14**.

The above-described features of the management and control systems associated with the combined battery and ultracapacitor systems may provide a variety of advantages over existing systems. For example, in certain embodiments, the combination of a high energy density battery and high power ultracapacitor at voltages within a range from approximately 24V to approximately 120V may provide advantages for a variety of types of vehicle applications, such as micro-hybrid and mild-hybrid, to improve the fuel efficiency and reduce the CO2 emissions of such vehicles. As noted above, providing combined battery and ultracapacitor systems in the foregoing voltage range may offer a variety of benefits.

More specifically, in certain instances, the size of a Pb-acid battery for SLI may be determined by both the cold cranking current at low temperatures (a power-related requirement) as well as the electric load of the vehicle (e.g., lights, electronics, chassis electrifications, etc.), which is an energy-related requirement. Some current Pb-acid batteries may have an energy density of approximately 40 Wh/kg, a capacity of approximately 70 Ah, and a voltage around 12V. Accordingly such batteries may typically supply a cold cranking current around 700 Ah at −18° C. In some instances, it may be desirable to improve the density of power and energy that energy source systems are capable of providing. For example, some mild-hybrid vehicles are equipped with a motor/generator in a parallel configuration allowing the engine to be turned off when the car is coasting, braking, or stopped, yet restart quickly. Accordingly, such demands may require the energy storage device in such mild hybrid vehicles to have higher power and energy output than non-hybrid or electric SLI vehicles.

Again, by providing battery and ultracapacitor combination systems at voltages within a range from approximately 24V to approximately 120V, a variety of advantages may be realized. That is, by combining a variety of battery types and ultracapacitors into a single system, the benefits associated with each technology type may be realized in a single device. In certain embodiments, the Li-ion battery technology may provide an energy density up to approximately 200 Wh/kg (which may be approximately 5 times that of traditional Pb-acid batteries). However, some Li-ion batteries may have a discharge rate of approximately 2 C at −18° C., which is lower than the Pb-acid battery cold cranking performance (e.g., approximately 10 C). Additionally, ultracapacitors or hybrid ultracapacitors may demonstrate high power density of approximately 10 kW/kg at room temperature (or a power density reaching up to approximately 1 kW/kg at approximately −30° C.). Presently disclosed embodiments of combination energy source systems may combine the advantages of one or more of these battery types with the advantages of the ultracapacitors into a single device. Still further, by providing systems in the range from approximately 24V to approximately 120V, the resistance heat loss may be reduced at high power output, thus providing additional advantages over single device systems and systems provided in lower voltage ranges.

To facilitate back-compatibility, retrofitting, battery replacement, physical support and electrical connection, it is presently contemplated that the battery and ultracapacitor, and battery-ultracapacitor-control circuitry combinations discussed in the present disclosure may be physically packaged together in an enclosure having a form factor that conforms to conventional battery packaging. That is, a shell or enclosure may be employed for housing combinations of batteries, ultracapacitors, and, where desired, control circuitry of the type discussed herein that is similar to or identical to those used with conventional Pb-acid or other battery types. The enclosures may deviate from conventional ones in certain respects, or be colored or labeled differently to clearly indicate that the replacement includes these internal components, although it is contemplated that features such as physical dimensions useful for placing and securing the devices, such as in vehicle applications, and locations and dimensions of terminals may be the same as or sufficiently similar to the conventional batteries that they replace to permit such replacement with little or no alteration of the existing supports or wiring.

FIG. **21** illustrates an exemplary standard battery enclosure **246** that is internally configured to house one or more batteries **248** or cells and one or more ultracapacitors **250**. Optionally as well, the enclosure may contain control circuitry **252**, regulation circuitry, and so forth, supported on one or multiple circuit boards. The physical dimensions of the enclosure may conform to existing standards for the particular battery type and application that the new battery is intended to replace. In particular, in the illustration of FIG. **21**, the enclosure has a height **254**, a width **256**, and a depth **258** that are substantially the same as dimensions of a selected standard battery. In this example, the battery terminals **260** are situated in top positions offset from the battery centerline. FIG. **22** shows another exemplary battery enclosure **262** having dimensions that conform and a unique shape that may conform to those of a desired battery that the new assembly and circuitry are intended to replace. In this case, terminals may be located on the top of the enclosure, or on a front side, as indicated by reference numeral **264**. Moreover, the standard form factors will include mounting or securement features, such as holddowns and so forth, as indicated generally by reference numeral A in FIG. **22**.

As will be appreciated by those skilled in the art, certain industry standards have been developed for use in configuring the physical packaging of batteries for many applications. For example, the Battery Council International (BCI) is a trade association that sets certain standards for vehicle batteries. A number of battery groups and sizes have been specified by the BCI. The listing below provides examples of certain of these:

BCI Group Number	Typical Maximum Overall Dimensions Millimeters L	W	H	Inches L	W	H
PASSENGER CAR AND LIGHT COMMERCIAL_BATTERIES 12-VOLT (6 CELLS)						
21	208	173	222	8 3/16	6 13/16	8 3/4
22F	241	175	211	9 1/2	6 7/8	8 5/16
22HF	241	175	229	9 1/2	6 7/8	9
22NF	240	140	227	9 7/16	5 1/2	8 15/16
22R	229	175	211	9	6 7/8	8 5/16
24	260	173	225	10 1/4	6 13/16	8 7/8
24F	273	173	229	10 3/4	6 13/16	9
24H	260	173	238	10 1/4	6 13/16	9 3/8
24R	260	173	229	10 1/4	6 13/16	9
24T	260	173	248	10 1/4	6 13/16	9 3/4
25	230	175	225	9 1/16	6 7/8	8 7/8
26	208	173	197	8 3/16	6 13/16	7 3/4
26R	208	173	197	8 3/16	6 13/16	7 3/4
27	306	173	225	12 1/16	6 13/16	8 7/8
27F	318	173	227	12 1/2	6 13/16	8 15/16
27H	298	173	235	11 3/4	6 13/16	9 1/4
29NF	330	140	227	13	5 1/2	8 15/16
31	325	167	238	12 13/16	6 9/16	9 3/8
31A	325	167	238	12 13/16	6 9/16	9 3/8
31T	325	167	238	12 13/16	6 9/16	9 3/8
33	338	173	238	13 5/16	6 13/16	9 3/8
34	260	173	200	10 1/4	6 13/16	7 7/8
34/78	260	175	200	10 1/16	6 7/8	7 7/8
34R	260	173	200	10 1/4	6 15/16	7 7/8
35	230	175	225	9 1/16	6 7/8	8 7/8
36R	263	183	206	10 3/8	7 1/4	8 1/8
40R	277	175	175	10 15/16	6 7/8	6 7/8
41	293	175	175	11 3/16	6 7/8	6 7/8
42	243	173	173	9 5/16	6 13/16	6 13/16
43	334	175	205	13 1/8	6 7/8	8 1/16
45	240	140	227	9 7/16	5 1/2	8 15/16
46	273	173	229	10 3/4	6 13/16	9
47	246	175	190	9 11/16	6 7/8	7 1/2
48	306	175	192	12 1/16	6 7/8	7 9/16
49	381	175	192	15	6 7/8	7 3/16
50	343	127	254	13 1/2	5	10
51	238	129	223	9 3/8	5 1/16	8 13/16
51R	238	129	223	9 3/8	5 1/16	8 13/16
52	186	147	210	7 5/16	5 13/16	8 1/4
53	330	119	210	13	4 11/16	8 1/4
54	186	154	212	7 5/16	6 1/16	8 3/8
55	218	154	212	8 5/8	6 1/16	8 3/8
56	254	154	212	10	6 1/16	8 3/8
57	205	183	177	8 1/16	7 3/16	6 15/16
58	255	183	177	10 1/16	7 3/16	6 15/16
58R	255	183	177	10 1/16	7 3/16	6 15/16
59	255	193	196	10 1/16	7 5/8	7 3/4
60	332	160	225	13 1/16	6 5/16	8 7/8
61	192	162	225	7 9/16	6 3/8	8 7/8
62	225	162	225	8 7/8	6 3/8	8 7/8
63	258	162	225	10 3/16	6 3/8	8 7/8
64	296	162	225	11 11/16	6 3/8	8 7/8
65	306	190	192	12 1/16	7 1/2	7 9/16
70	208	179	196	8 3/16	7 1/16	7 11/16
71	208	179	216	8 3/16	7 1/16	8 1/2
72	230	179	210	9 1/16	7 1/16	8 1/4
73	230	179	216	9 1/16	7 1/16	8 1/2
74	260	184	222	10 1/4	7 1/4	8 3/4
75	230	179	196	9 1/16	7 1/16	7 11/16
75/25	238	173	197	9 3/8	6 13/16	7 3/4
76	334	179	216	13 1/8	7 1/16	8 1/2
78	260	179	196	10 1/4	7 1/16	7 11/16
85	230	173	203	9 1/16	6 13/16	8
86	230	173	203	9 1/16	6 13/16	8
90	246	175	175	9 11/16	6 7/8	6 7/8
91	280	175	175	11	6 7/8	6 7/8
92	317	175	175	12 1/2	6 7/8	6 7/8
93	354	175	175	15	6 7/8	6 7/8
95R	394	175	190	15 9/16	6 7/8	7 1/2
96R	242	173	175	9 9/16	6 13/16	6 7/8
97R	252	175	190	9 15/16	6 7/8	7 1/2
98R	283	175	190	11 3/16	6 7/8	7 1/2

-continued

BCI Group Number	Typical Maximum Overall Dimensions Millimeters L	W	H	Inches L	W	H
PASSENGER CAR AND LIGHT COMMERCIAL BATTERIES 6-VOLT(3 CELLS)						
1	232	181	238	9 1/8	7 1/8	9 3/8
2	264	181	238	10 3/8	7 1/8	9 3/8
2E	492	105	232	19 7/16	4 1/8	9 1/8
2N	254	141	227	10	5 9/16	8 15/16
17HF	187	175	229	7 3/8	6 7/8	9
HEAVY-DUTY COMMERCIAL BATTERIES 12-VOLT (6 CELLS)						
4D	527	222	250	20 3/4	8 3/4	9 7/8
6D	527	254	260	20 3/4	10	10 1/4
8D	527	283	250	20 3/4	11 1/8	9 7/8
28	261	173	240	10 5/16	6 13/16	9 7/16
29H	334	171	232	13 1/8	6 3/4	9 1/8 10
30H	343	173	235	13 1/2	6 13/16	9 1/4 10
31	330	173	240	13	6 13/18	9 7/16
ELECTRIC VEHICLE BATTERIES 6-VOLT (3 CELLS)						
GC2	264	183	270	10 3/8	7 3/16	10 5/8
GC2H	264	183	295	10 3/8	7 3/16	11 5/8

It should be noted that this listing is not exhaustive, and other form factors may be utilized. A number of variations in these form factors may be due to such factors as rated voltages, capacity, application, the physical mounting requirements (which may vary for different original equipment manufacturers), the terminal types and configurations, the country or region, and so forth. Terminals may be placed, for example, in top, front, side or a combination of locations. Holddown ledges and features may similarly vary with the different enclosures.

The particular shape and physical configuration of the internal battery, the ultracapacitors, and any included circuitry may be adapted for the internal space and layout available within the particular enclosures. It is contemplated that locating and securing structures, isolating structures, interconnects and so forth will be adapted within the enclosures or placed in the enclosures during assembly to locate and hold the batteries, ultracapacitors and any related circuitry in place, and to interconnect these as required for their proper electrical function. Many variations of such structures may be designed, and their particular configurations are considered to be within the ability of those skilled in the art without undue experimentation.

It should also be noted that the particular battery, ultracapacitors and any included circuitry may be of any desired type, rating, size and so forth, such as those described above. It is presently contemplated that the battery systems thus provided may be different, but in many or most cases will be such as to permit retrofitting of existing conventional batteries, such as Pb-acid batteries, glass mat batteries, and so forth. For original equipment manufacturers, such as vehicle manufacturers, the new battery systems may be installed as original equipment in the place of conventional batteries with little or no alteration in the location or physical configuration of support structures and electrical connections. The battery systems may thus be used in connection with conventional internal combustion engines, hybrid vehicles, electric vehicles, and forth. Moreover, the battery systems may be used for non-vehicular applications, such as for

home or building energy storage, energy generation systems (e.g., wind or engine generators) and so forth.

It should also be noted that in certain implementations, the system enclosure may be made somewhat smaller than the standard dimensions for existing batteries, and various adapters, shims, and so forth may be used to more closely conform to existing mounting structures. Such adapters and similar hardware may be obtained in kits, sold separately or with the battery systems, and may be designed to allow the battery systems to fit within particular models or families of vehicles. As noted above, such adapters and hardware may also allow for the use of enclosures of irregular or non-standard shapes. Certain of these adapters are illustrated in FIG. **22**, and labeled generally "A". These may fit on sides, the base, the top, or generally anywhere on the enclosure that may not directly conform with the desired mounting position or structures. Additional information regarding BCI battery standards, technical specifications and replacement is available in the BCI Battery Technical Manual and the BCI Battery Replacement Data Book, both available from BCI of Chicago, Ill.

It should further be noted that a variety of other circuits not illustrated herein may be provided and utilized in an energy source device in accordance with presently disclosed embodiments. For example, in certain embodiments, the energy source system **10** may include multiple battery packs, as described in detail in U.S. Provisional Patent Application No. 61/477,730, entitled "Multiple Battery System for Vehicle Applications," filed Apr. 21, 2011, which is hereby incorporated by reference. For example, in one embodiment, the energy source system **10** may include a first battery pack configured to provide electrical power to an engine starting system of a vehicle and a second battery pack configured to provide electrical power to at least one electronic system of the vehicle. Further, the battery packs may, for example, be controlled by a suitable controller, such as controller **26**, and the battery packs may be provided in addition to or in place of the batteries and/or ultracapacitor systems disclosed herein, depending on a variety of implementation-specific parameters.

Still further, as shown in the embodiment of FIG. **16**, an energy source system **180** includes a differential state of charge (SOC) energy storage device **182** having a housing **184** that encloses a low SOC energy storage device **186** and a high SOC energy storage device **188** in a single enclosure. In certain embodiments, the energy storage devices may be any combination of devices capable of storing energy and/or charge. For example, in some embodiments, the energy storage devices may include but are not limited to capacitors, ultracapacitors, a capacitive electrode coupled to or contained within an energy storage device, electrochemical storage devices (e.g., lithium-based batteries, nickel-based batteries, lead-based batteries, etc.), fuel cells, or any other suitable material or device capable of storing energy.

As illustrated in FIG. **16**, the low SOC device **186** includes a negative terminal **190** coupled to ground **192** and a positive terminal **193** that is coupled to the device output **194**. Similarly, the high SOC device **188** includes a negative terminal **196** coupled to ground **198** and a positive terminal **200** that is coupled to the device output **194**. By combining the relatively low SOC device **186** with the relatively high state of charge device **188** in the housing **184**, the charge acceptance and charging rate of the differential SOC device **182** may be improved compared to single SOC devices, as described in more detail below.

It should be noted that the low SOC device **186** and the high SOC device may be any suitable devices that have different states of charge relative to one another. For example, in one embodiment, the low SOC device may be a battery type that operates at approximately 30% SOC, and the high SOC device may be a battery type that operates at approximately 80% SOC. In some embodiments, the low SOC device and/or the high SOC device may be a Li-ion battery, an ultracapacitor, a Pb-acid battery or any combination or sub-combination of the foregoing devices.

An example of a voltage versus SOC plot **202** for two such example devices is shown in FIG. **17**. As shown, the plot **202** includes a voltage axis **204** and a percentage SOC axis **206**. The plot **202** further includes a curve **208** corresponding to the operational profile of the low SOC device **186** and a plot **210** corresponding to the operational profile of the high SOC device **188**. It should be noted that the differences between the curves **208** and **210** may be attributed, for example, to the operational differences between battery types. For instance, in one embodiment, the curves **208** and **210** may correspond to two different Li-ion batteries, each having a different voltage due to a different battery chemistry, anode material, cathode material, or any other parameter of the battery.

For further example, FIG. **18** illustrates a voltage versus SOC plot **212** for two example devices having different battery chemistries. Specifically, the plot **212** includes a curve **214** corresponding to the operational profile of the low SOC device **186** and a plot **216** corresponding to the operational profile of the high SOC device **188**. In this embodiment, the low SOC device may, for example, be a Li-ion battery, and the high SOC device may, for example, by a Pb-acid battery. Here again, the differences between the curves **214** and **216** may be attributed, for example, to the differences in battery chemistry between the devices **186** and **188**.

During operation, the combination of the low SOC device **186** and the high SOC device **188** may offer a variety of performance benefits as compared to single SOC systems or as compared to systems in which the single SOC device is scaled to a larger size and capability. For example, in certain embodiments, the low SOC device **186** may be charged at a higher rate than the high SOC device **188**, thus offering advantages, for example, during regenerative breaking of a vehicle when the high power charging and charge acceptance of the low SOC device **186** may offset the relatively low charge acceptance of the high SOC device **188**. Accordingly, a smaller overall housing **182** may be provided to house a differential SOC device as compared to a single SOC device having the same performance abilities with respect to capturing the regenerative energy during braking. The foregoing feature may be realized, for example, in an embodiment in which a Li-ion battery and a Pb-acid battery are combined into a single differential SOC device.

These and other advantages of the differential SOC device **182** may be better understood by considering the plots **218** and **220** illustrated in FIGS. **19** and **20**. Specifically, the plot **218** illustrated in FIG. **19** includes a charging power capability axis **221** and a voltage axis **222**. The plot **218** further includes a main battery plot **224**, an auxiliary battery plot **226**, an increased size battery plot **228**, and a differential SOC combination plot **230**. As shown in FIG. **19**, a distance **232** between the phantom larger size curve **228** and the differential SOC combination plot **230** visually illustrates the advantage in charging power capability that may be gained by combining the low SOC device **186** and the high SOC device **188** in the housing **182**, as opposed to scaling up the size and capability of a single SOC device. Again, a variety of benefits may be gained from combining the

devices **186** and **188** into the housing **184**, such as an improved charging capability when the device **182** is approximately full.

The plot **220** illustrated in FIG. **20** includes the charging power capability axis **221** and a SOC axis **234**. The plot **220** further includes a main battery plot **236**, an auxiliary battery plot **238**, an increased size battery plot **240**, and a differential SOC combination plot **242**. As shown in FIG. **20**, a distance **244** between the phantom larger size curve **240** and the differential SOC combination plot **242** visually illustrates the advantage in charging power capability that may be gained by combining the low SOC device **186** and the high SOC device **188** in the housing **182**, as opposed to scaling up the size and capability of a single SOC device. Here again, it can be seen that various advantages may be gained from combining the devices **186** and **188** into the housing **184**.

According to the various exemplary embodiments, a combined battery and ultracapacitor system is provided for use in a wide variety of vehicle applications to provide a number of advantages. The parallel configuration of the ultracapacitors provides the necessary short duration and high capacity discharge necessary to meet the cold cranking current requirements of the vehicle. Also, the system permits the use of various battery technologies for storing and supplying the electricity needed for other electrical loads of the vehicle and stabilizing the electrical system voltage level during engine starts, which reduces the weight and size constraints imposed by many conventional vehicle battery and electrical systems. Further, the system permits utilizing the high power charge rate of the ultracapacitors to restore the energy during braking or stopping (e.g. regenerative braking). Additionally, as noted above, the battery and ultracapacitors may contain suitable management systems to monitor the parameters including temperature, current, and voltage to prevent them from deep-charging and discharging. Accordingly, all such variations are intended to be within the scope of this disclosure.

The various combined battery and ultracapacitor systems provided herein are adaptable and scalable to fit a wide variety of applications, including start/stop, micro-hybrid, and electric vehicle applications, and to suit a wide variety of voltage requirements. For example, in one embodiment, as shown in FIG. **23**, a vehicle **270** in the form of an automobile (e.g., a car) having a battery module or system **272** for providing all or a portion of the motive power for the vehicle **270**. In some embodiments, the vehicle **270** may be an electric vehicle (EV), a hybrid electric vehicle (HEV), a plug-in hybrid electric vehicle (PHEV), or any other type of vehicle using electric power for propulsion (collectively referred to as "electric vehicles"). Additionally, although illustrated as a car in FIG. **23**, the type of the vehicle **270** may be implementation-specific, and, accordingly, may differ in other embodiments, all of which are intended to fall within the scope of the present disclosure. For example, the vehicle **270** may be a truck, bus, industrial vehicle, motorcycle, recreational vehicle, boat, or any other type of vehicle that may benefit from the use of electric power for all or a portion of its propulsion power.

Further, although the battery module **272** is illustrated in FIG. **23** as being positioned in the trunk or rear of the vehicle **270**, according to other exemplary embodiments, the location of the battery module **272** may differ. For example, the position of the battery module **272** may be selected based on the available space within the vehicle **270**, the desired weight balance of the vehicle **270**, the location of other components used with the battery system (e.g., battery management systems, vents or cooling devices, etc.), and a variety of other implementation-specific considerations.

FIG. **24** illustrates a cutaway schematic view of the vehicle **270** provided in the form of an HEV according to a presently disclosed embodiment. In the illustrated embodiment, the battery module or system **272** is provided toward the rear of the vehicle **270** proximate a fuel tank **274**. However, in other embodiments, the battery module **272** may be provided immediately adjacent the fuel tank **274** or may be provided in a separate compartment in the rear of the vehicle **270** (e.g., a trunk) or may be provided elsewhere in the vehicle **270**. An internal combustion engine **276** is provided for times when the HEV utilizes gasoline power to propel the vehicle **270**. An electric motor **278**, a power split device **280**, and a generator **282** are also provided as part of the vehicle drive system. Such an HEV may be powered or driven by just the battery system **272**, by just the engine **276**, or by both the battery system **272** and the engine **276**. It should be noted that other types of vehicles and configurations for the vehicle electrical system may be used according to other embodiments, and that the schematic illustration of FIG. **24** should not be considered to limit the scope of the subject matter described in the present application. Indeed, according to various other embodiments, the size, shape, and location of the battery module or system **272**, the type of vehicle **270**, the type of vehicle technology (e.g., EV, HEV, PHEV, etc.), and the battery chemistry, among other features, may differ from those shown or described.

According to an embodiment, the battery module or system **272** is responsible for packaging or containing electrochemical cells or batteries, connecting the electrochemical cells to each other and/or to other components of the vehicle electrical system, and regulating the electrochemical cells and other features of the battery system **272**. For example, the battery module or system **272** may include features that are responsible for monitoring and controlling the electrical performance of the system, managing the thermal behavior of the system, containment and/or routing of effluent (e.g., gases that may be vented from a battery cell), and other aspects of the battery module or system.

Here again, it should also be noted that the present techniques also apply to storage and use of energy in vehicles that do not use or sometimes use electrical energy for propulsion. For example, such vehicles may include conventional internal combustion engines used for propulsion, or vehicles that may employ regenerative braking, but not use the resulting energy directly for propulsion. Moreover, the techniques may be particularly advantageous in any vehicle in certain use cases. For example, in so-called stop-start applications the vehicle engine or prime mover may be shut off at certain times (e.g., when stopped at an intersection) and restarted each time, resulting in a need for starting energy. Finally, it should be noted that the techniques may be advantageous for any of a range of cases both vehicular and non-vehicular, such as for driving accessories, electrical loads, and so forth.

As utilized herein, the terms "approximately," "about," "substantially," and similar terms are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. It should be understood by those of skill in the art who review this disclosure that these terms are intended to allow a description of certain features described and claimed without restricting the scope of these features to the precise numerical ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequen-

tial modifications or alterations of the subject matter described and claimed are considered to be within the scope of the invention as recited in the appended claims.

It should be noted that the term "exemplary" as used herein to describe various embodiments is intended to indicate that such embodiments are possible examples, representations, and/or illustrations of possible embodiments (and such term is not intended to connote that such embodiments are necessarily extraordinary or superlative examples).

The terms "coupled," "connected," and the like as used herein mean the joining of two members directly or indirectly to one another. Such joining may be stationary (e.g., permanent) or moveable (e.g., removable or releasable). Such joining may be achieved with the two members or the two members and any additional intermediate members being integrally formed as a single unitary body with one another or with the two members or the two members and any additional intermediate members being attached to one another.

It should be noted that the orientation of various elements may differ according to other exemplary embodiments, and that such variations are intended to be encompassed by the present disclosure.

It is also important to note that the construction and arrangement of the combined battery and ultracapacitor systems for vehicle applications as shown in the various exemplary embodiments is illustrative only. Although only a few embodiments of the present inventions have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible (e.g., variations in battery chemistry and material, quantities and capacities, selection of ultracapacitor size and capacity, etc.) without materially departing from the novel teachings and advantages of the subject matter disclosed herein. For example, the battery technologies may include any one or more of Li-ion, Pb-acid, Ni-M(H), Ni—Zn, or other battery technologies. Further, the balancing of the charge to the ultracapacitors may be accomplished by other suitable electronic components. Accordingly, all such modifications are intended to be included within the scope of the present invention as defined in the appended claims. The order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments. Other substitutions, modifications, changes and omissions may be made in the design, operating conditions and arrangement of the various exemplary embodiments without departing from the scope of the present inventions.

The invention claimed is:

1. An energy source system, comprising:

a housing comprising a positive terminal and a negative terminal;

a first electrochemical energy storage device comprising a Li-ion battery disposed in the housing and configured to operate at a first state of charge level, wherein the first state of charge level is 30%, and wherein the first electrochemical energy storage device is configured to receive regenerative energy from a regenerative braking event associated with operation of a vehicle;

a second electrochemical energy storage device comprising a Pb-acid battery disposed in the housing and configured to operate at a second state of charge level, wherein the second state of charge level is 80%, and wherein the first electrochemical energy storage device comprises a greater charging rate than the second energy storage device; and

a controller disposed in the housing and coupled to the first electrochemical energy storage device and the second electrochemical energy storage device and configured to control the charging and discharging of the first electrochemical energy storage device and the second electrochemical energy storage device, wherein the controller is configured to control charging of the first electrochemical energy storage device to maintain the first state of charge level and to control charging of the second electrochemical energy storage device to maintain the second state of charge level, and wherein the controller is configured to control the first electrochemical energy storage device to discharge to meet a cold cranking requirement of an internal combustion engine of a vehicle and to control the second electrochemical energy storage device to discharge to provide energy for operation of the vehicle.

2. The energy source system of claim **1**, wherein the controller is configured to control one of the first electrochemical energy storage device or the second electrochemical energy storage device to supplement power provided by the other of the first electrochemical energy storage device or the second electrochemical energy storage device based on a rate of change of a current draw of the other of the first electrochemical energy storage device or the second electrochemical energy storage device.

3. An energy storage system, comprising:

a housing comprising a positive terminal and a negative terminal;

a first electrochemical energy storage device comprising a Li-ion battery disposed in the housing and comprising a first charging rate during charging of the energy storage system, wherein the first electrochemical energy storage device is configured to operate at a first state of charge of 30%;

a second electrochemical energy storage device comprising a Pb-acid battery disposed in the housing and comprising a second charging rate during charging of the energy storage system, wherein the first charging rate is greater than the second charging rate, and the second electrochemical energy storage device is configured to operate at a second state of charge of 80%; and

a controller coupled to the first energy storage device and the second energy storage device and configured to control charging of the energy storage system during a regenerative braking event associated with operation of a vehicle such that the first energy storage device is configured to receive regenerative energy associated with the regenerative braking event at the first charging rate, the controller is configured to control the Li-ion battery to discharge to meet a cold cranking requirement of the vehicle and the control the second electrochemical energy storage device to discharge to provide energy for operation of the vehicle, and the controller is configured to control charging of the first electrochemical energy storage device to maintain the first state of charge and to control charging of the second electrochemical energy storage device to maintain the second state of charge.

4. An energy source system, comprising:

a housing comprising a positive terminal and a negative terminal;

a first electrochemical energy storage device comprising a Li-ion battery disposed in the housing and comprising a first charge acceptance rate, wherein the first electrochemical energy storage device is operated by a con-

troller to meet a cold cranking requirement of an internal combustion engine of a vehicle while discharging, and the first electrochemical energy storage device is configured to operate at 30% state of charge (SOC);

a second electrochemical energy storage device comprising a Pb-acid battery disposed in the housing and comprising a second charge acceptance rate, wherein the second charge acceptance rate is less than the first charge acceptance rate, the second electrochemical energy storage device is configured to discharge to provide energy for operation of the vehicle, and the second electrochemical energy storage device is configured to operate at 80% SOC; and

a controller coupled to the first electrochemical energy storage device and the second electrochemical energy storage device, wherein the controller is configured to control charging of the first electrochemical energy storage device to maintain the 30% SOC and to control charging of the second electrochemical energy storage device to maintain the 80% SOC.

5. The system of claim **4**, wherein the controller is disposed within the housing.

6. The system of claim **4**, wherein the controller is configured to control the first electrochemical energy storage device to receive regenerative energy associated with a regenerative braking event of a vehicle at the first charge acceptance rate.

7. An energy source system, comprising:

a vehicle;

an energy storage device disposed in the vehicle, wherein the energy storage device comprises:

a housing comprising a positive terminal and a negative terminal;

a first electrochemical energy storage device comprising a Li-ion battery disposed in the housing and configured to operate at a first state of charge level, wherein the first electrochemical energy storage device is operated by a controller to meet a cold cranking requirement of an internal combustion engine of the vehicle, and wherein the controller is configured to control charging of the first electrochemical energy storage device to maintain the first state of charge level, and the first state of charge level is 30%;

a second electrochemical energy storage device comprising a Pb-acid battery disposed in the housing and configured to operate at a second state of charge level to discharge to provide energy for operation of the vehicle, wherein the second state of charge level is greater than the first state of charge level, wherein the first electrochemical energy storage device comprises a greater charging rate than the second energy storage device, and wherein the controller is configured to control charging of the second electrochemical energy storage device to maintain the second state of charge level, and the second state of charge level is 80%; and

a controller coupled to the first electrochemical energy storage device and the second electrochemical energy storage device, wherein the controller is configured to control charging of the first electrochemical energy storage device to maintain the first state of charge level and to control charging of the second electrochemical energy storage device to maintain the second state of charge level.

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