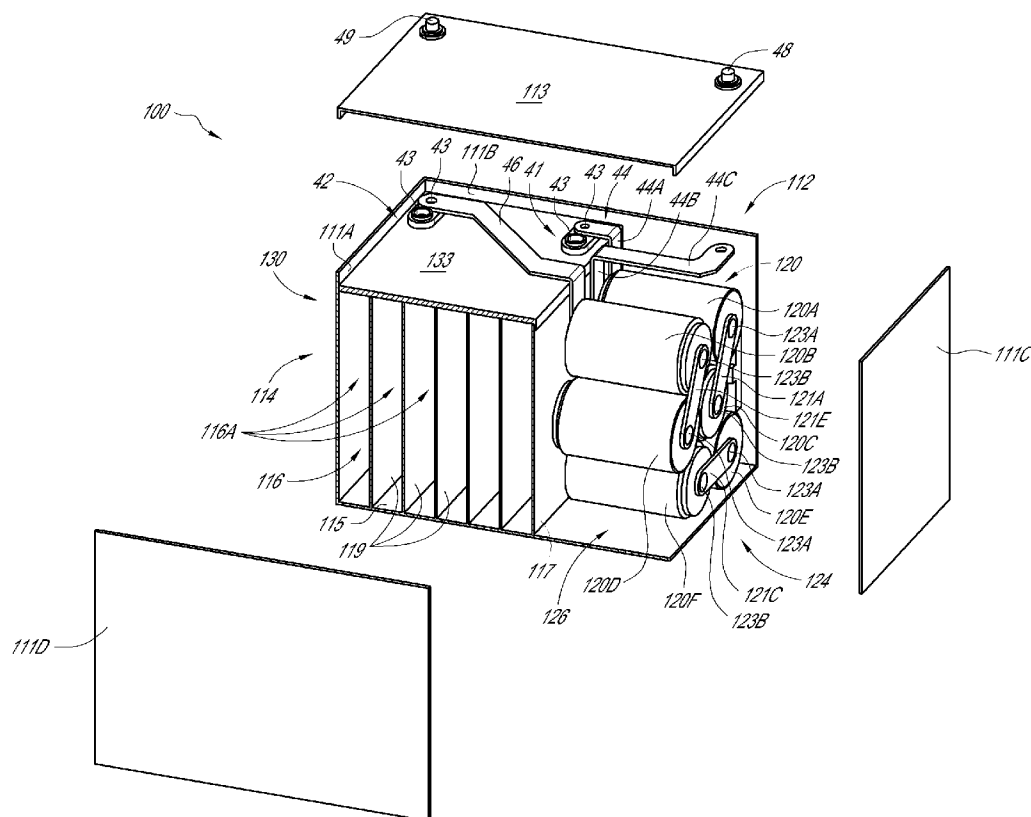




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(19) **United States**(12) **Patent Application Publication**
Cowperthwaite et al.(10) **Pub. No.: US 2013/0266826 A1**(43) **Pub. Date: Oct. 10, 2013**(54) **ULTRACAPACITOR/BATTERY
COMBINATION AND BUS BAR SYSTEM**(52) **U.S. Cl.**
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WI (US)(57) **ABSTRACT**(21) Appl. No.: **13/797,496**(22) Filed: **Mar. 12, 2013****Related U.S. Application Data**(60) Provisional application No. 61/610,425, filed on Mar.
13, 2012, provisional application No. 61/610,417,
filed on Mar. 13, 2012, provisional application No.
61/610,399, filed on Mar. 13, 2012.**Publication Classification**(51) **Int. Cl.**
H01M 16/00 (2006.01)
H01M 2/02 (2006.01)

This disclosure provides systems, methods and apparatus for a combined battery/capacitor energy storage device. The energy storage device includes an energy storage device housing, with a battery housing portion, a capacitor housing portion, and a housing lid. The energy storage device includes a battery disposed within the battery housing portion. The battery includes a first battery terminal extending through a battery lid enclosing the battery housing portion. The energy storage device includes a capacitor disposed within the capacitor housing portion and connected in parallel with the battery. The capacitor includes a first capacitor terminal. The energy storage device includes a first bus bar electrically connecting the first battery terminal and the first capacitor terminal. The energy storage device includes a first external device terminal extending through the energy storage device housing and configured to electrically connect to the first battery terminal and the bus bar.



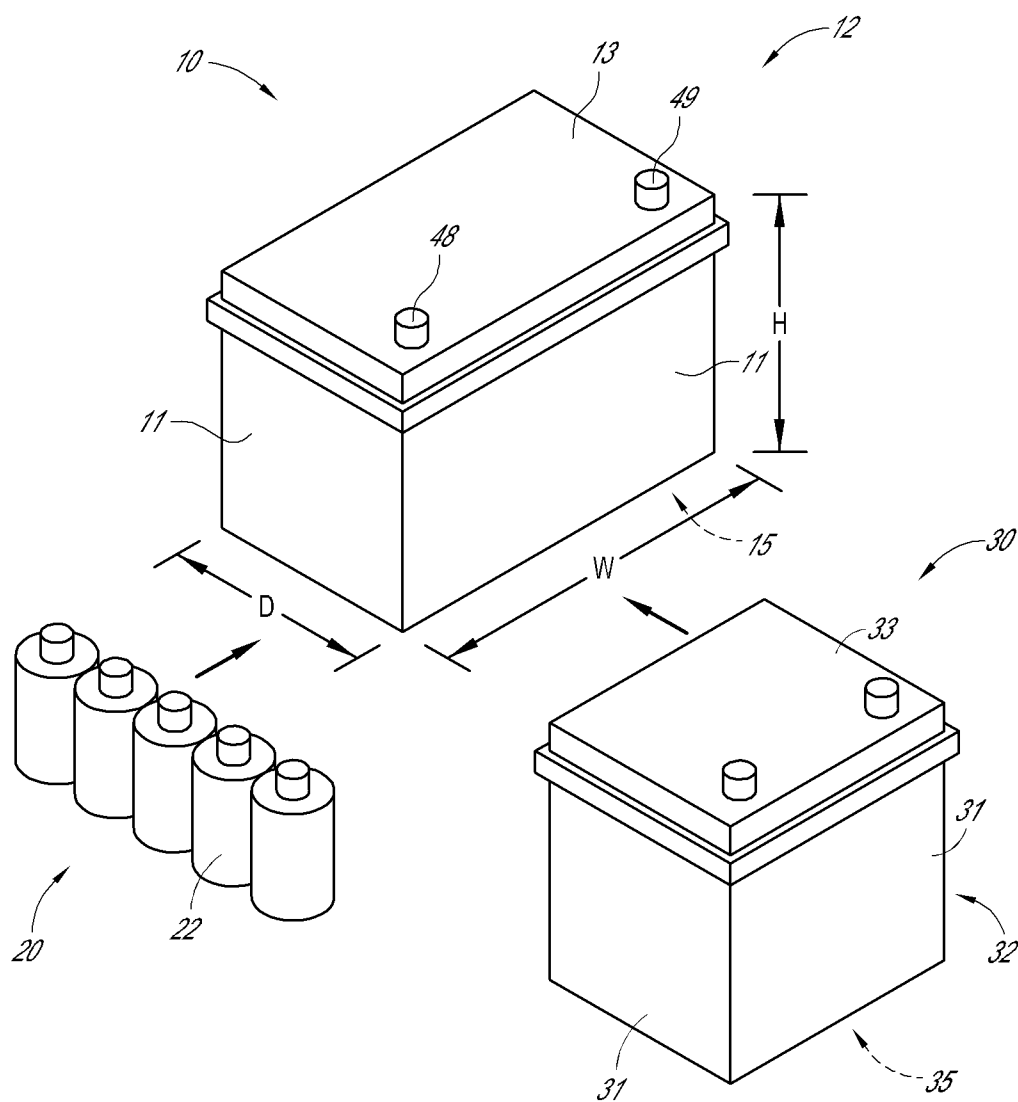
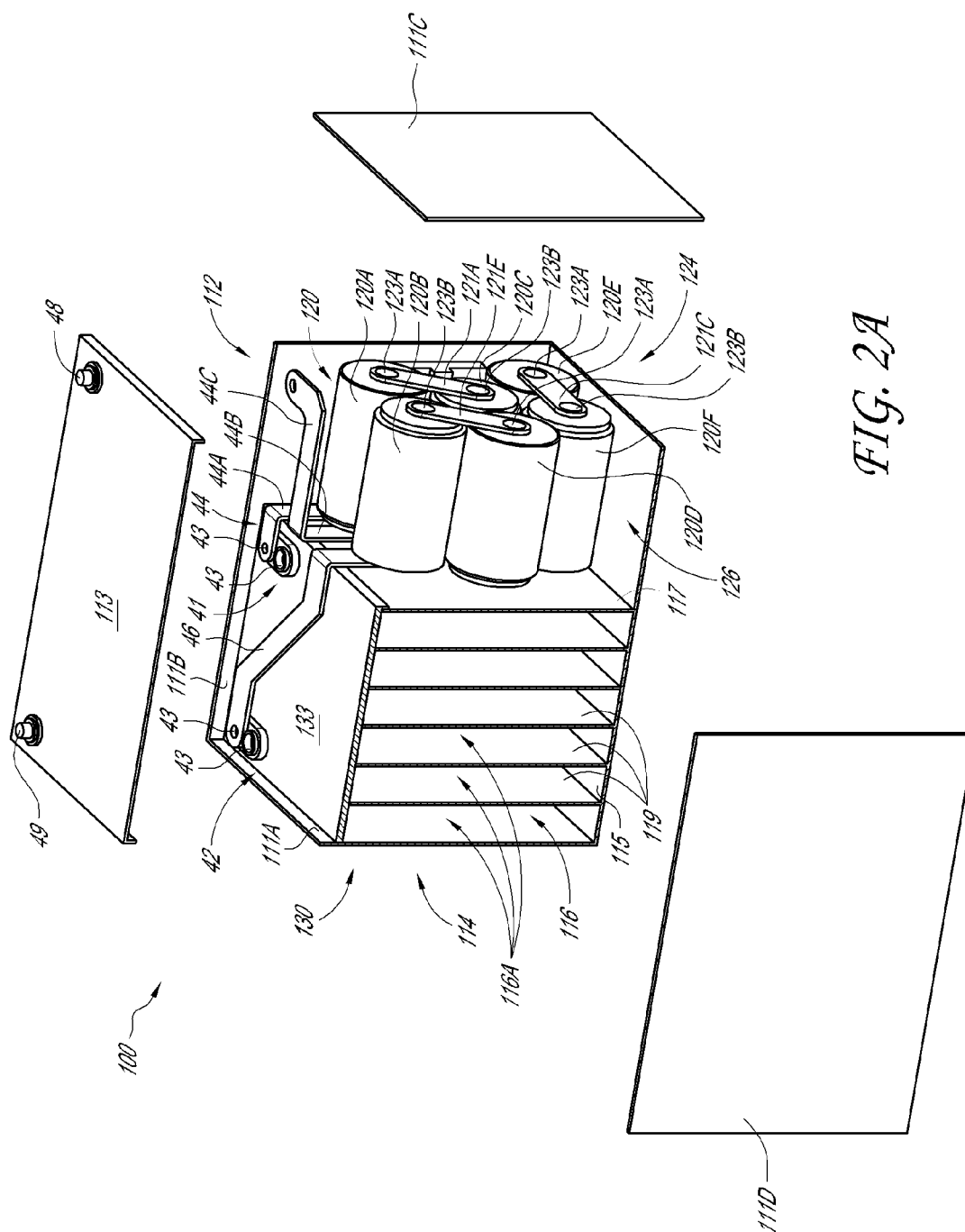


FIG. 1



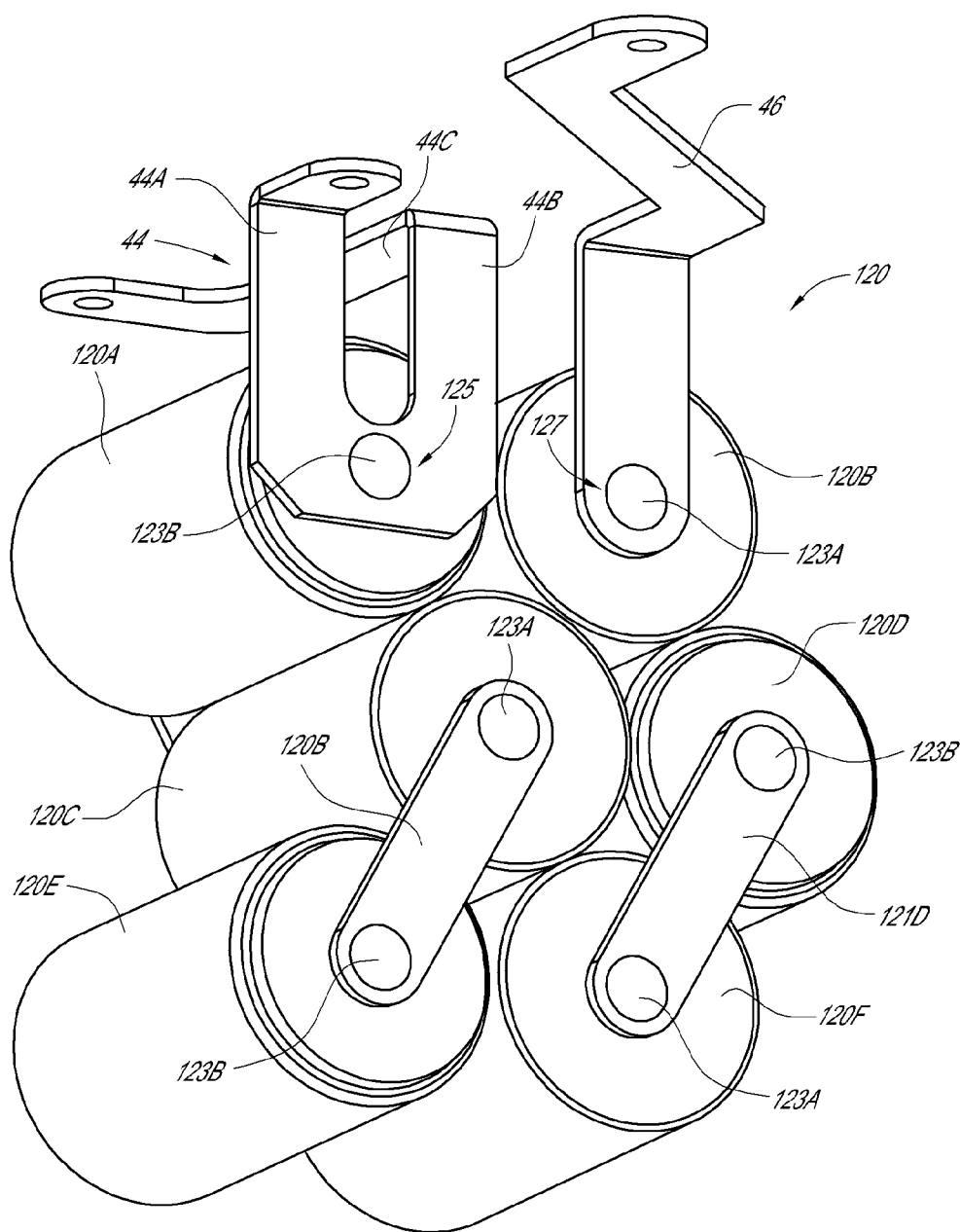


FIG. 2B

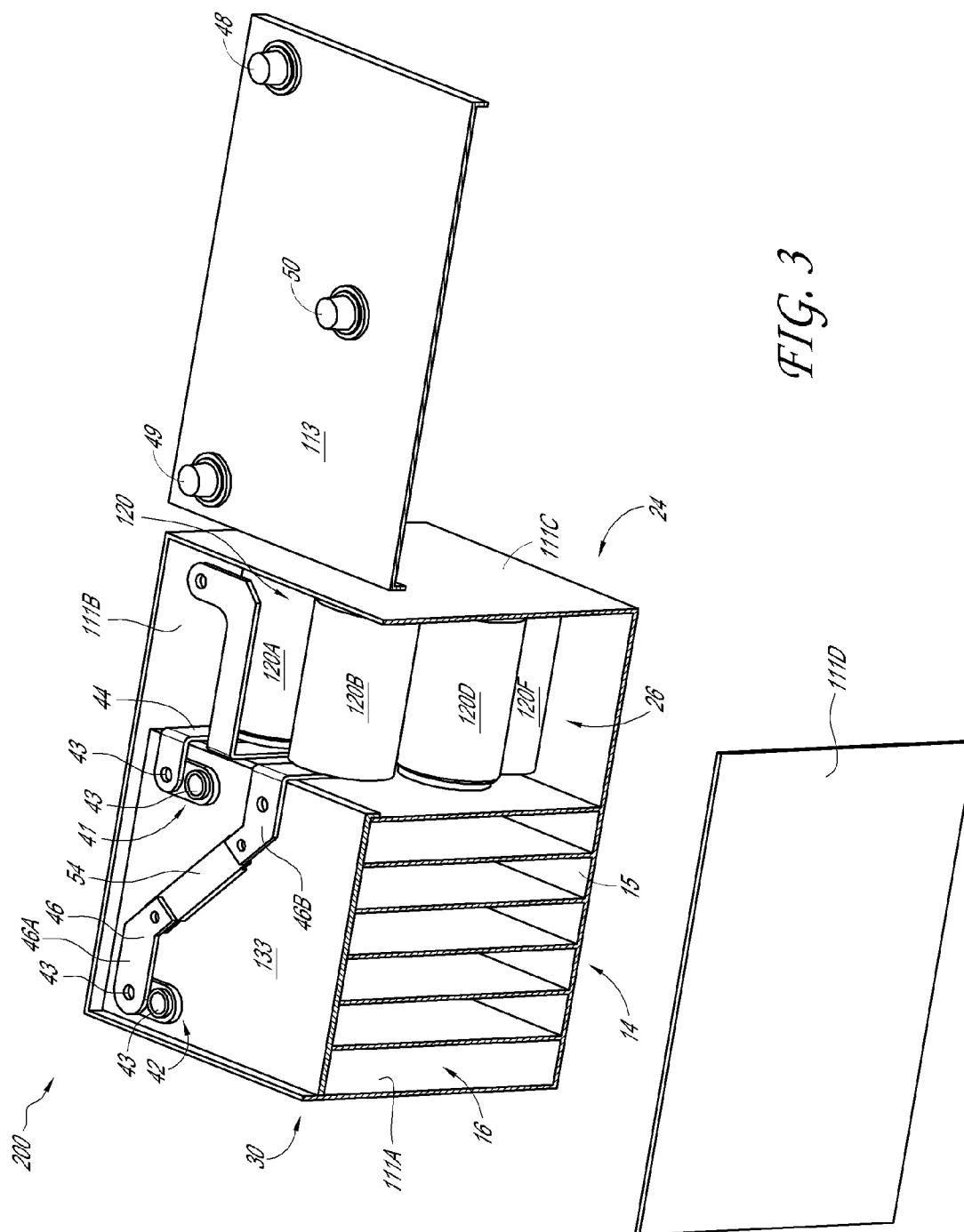


FIG. 4

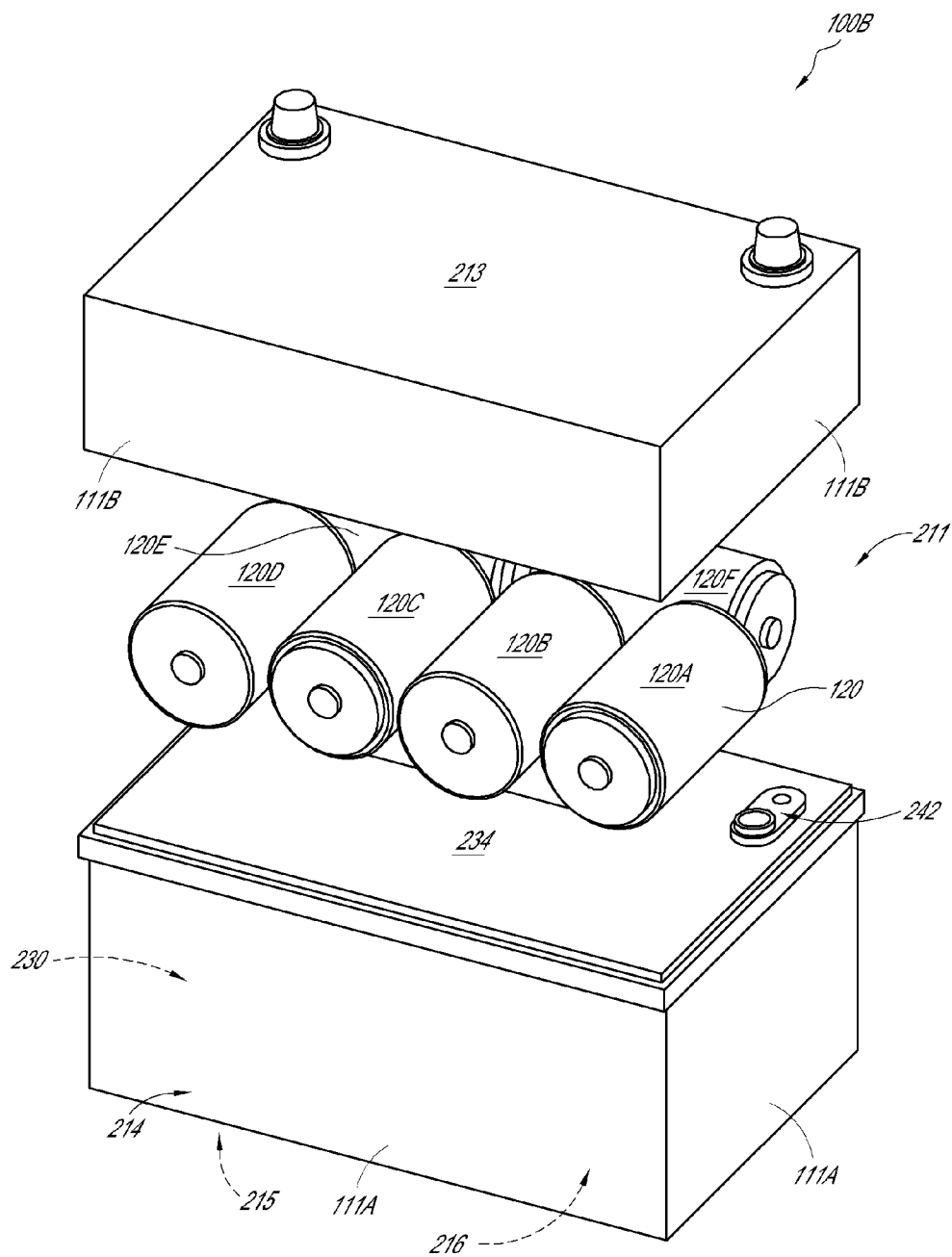


FIG. 5

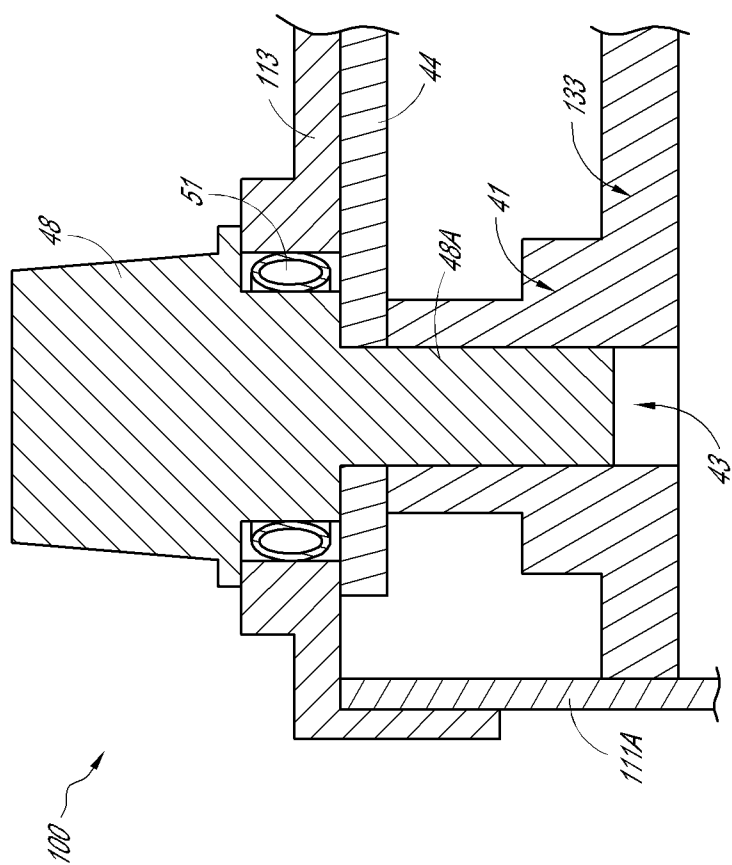


FIG. 6A

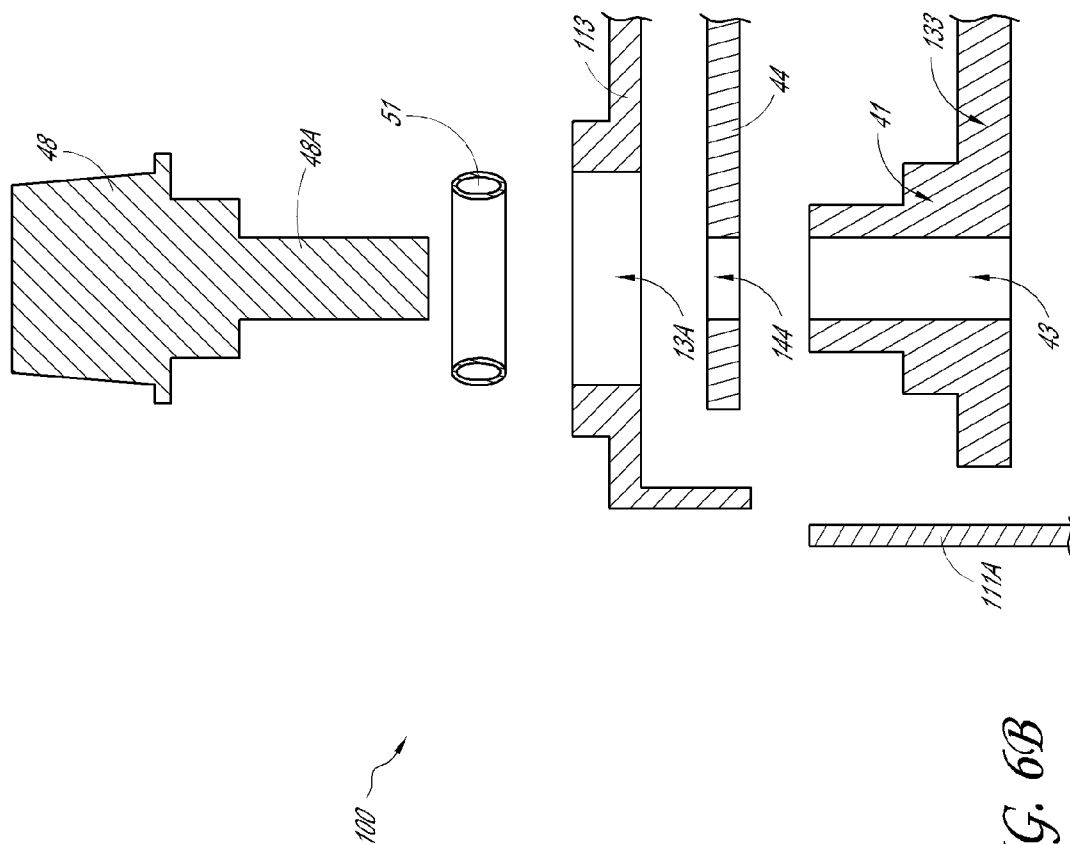


FIG. 6B

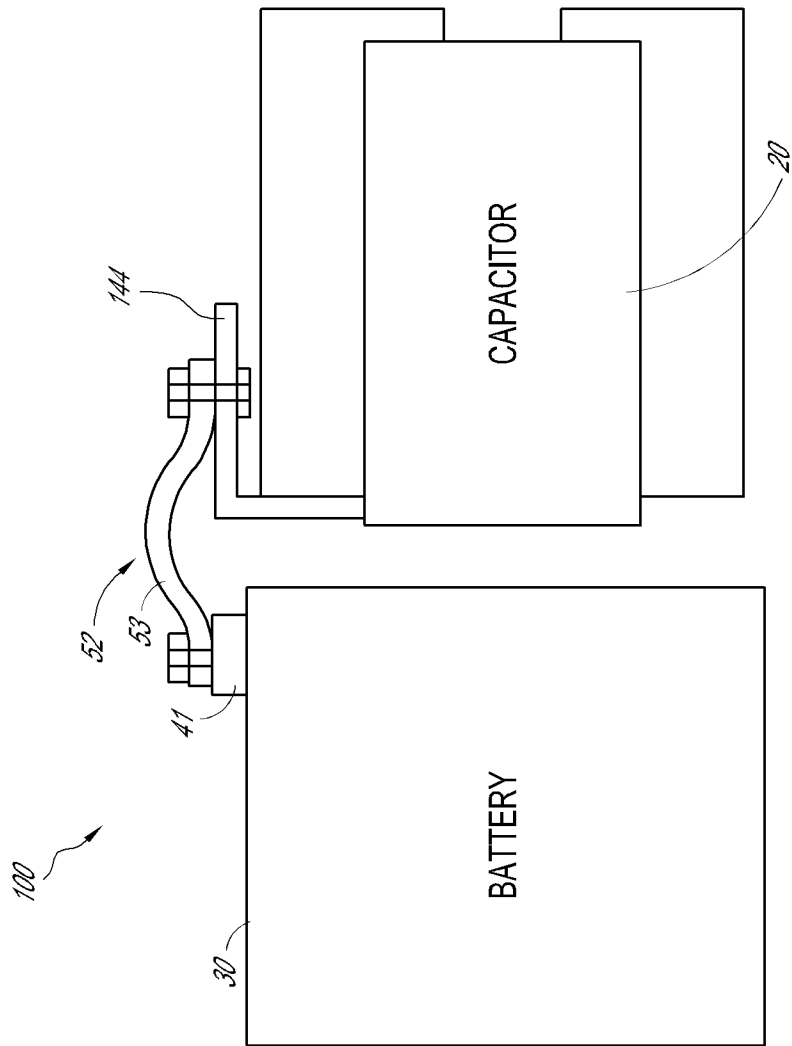


FIG. 7

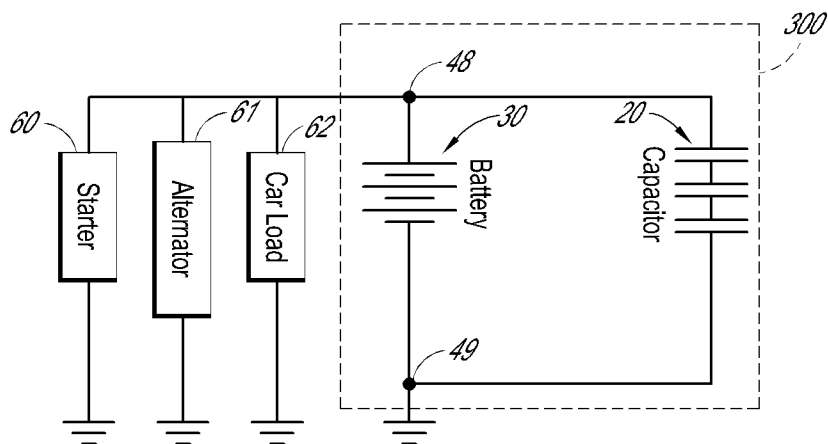


FIG. 8

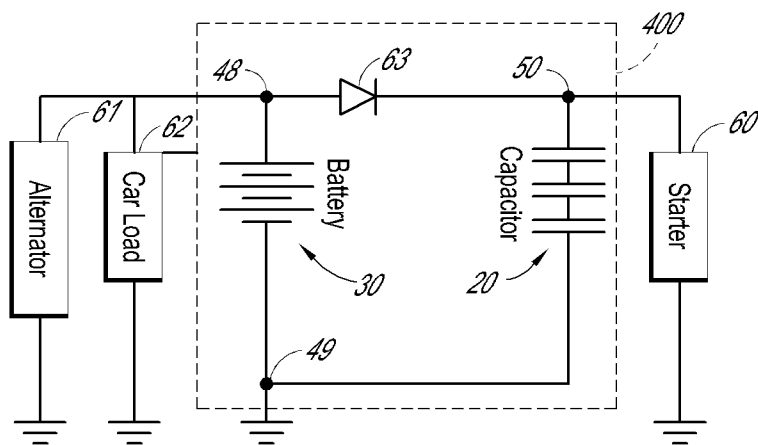


FIG. 9

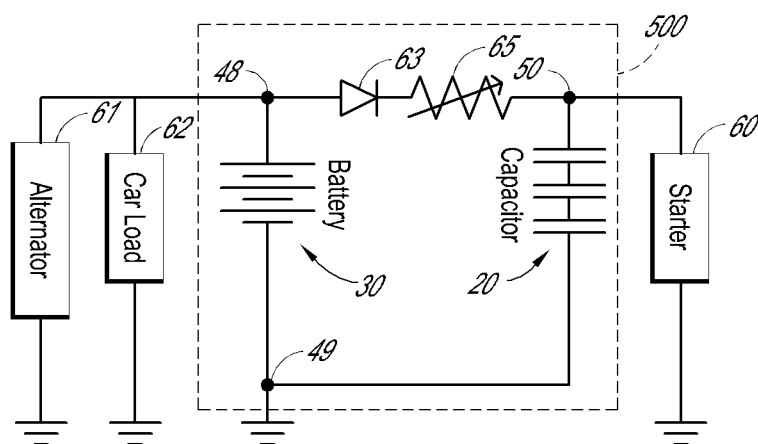


FIG. 10

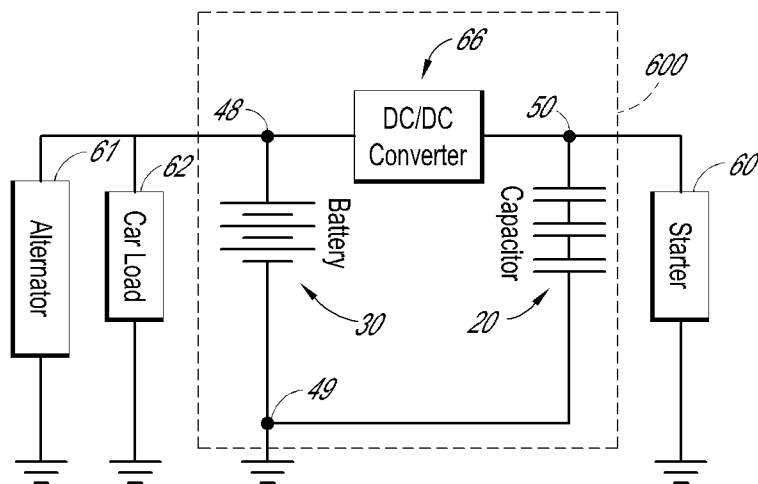


FIG. 11

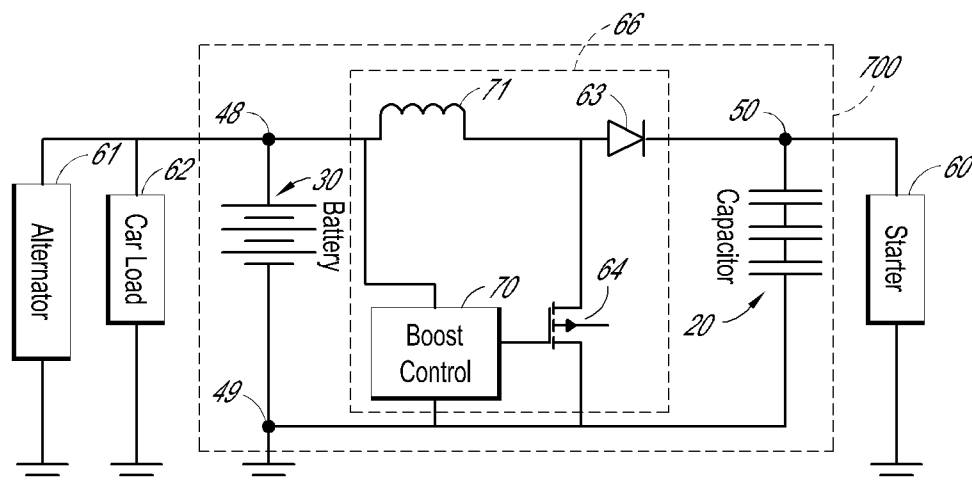


FIG. 12

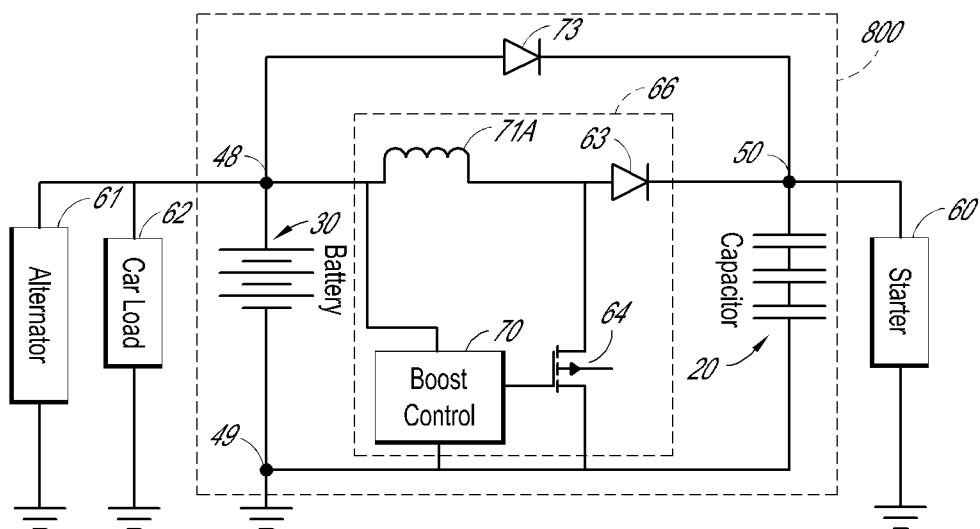


FIG. 13

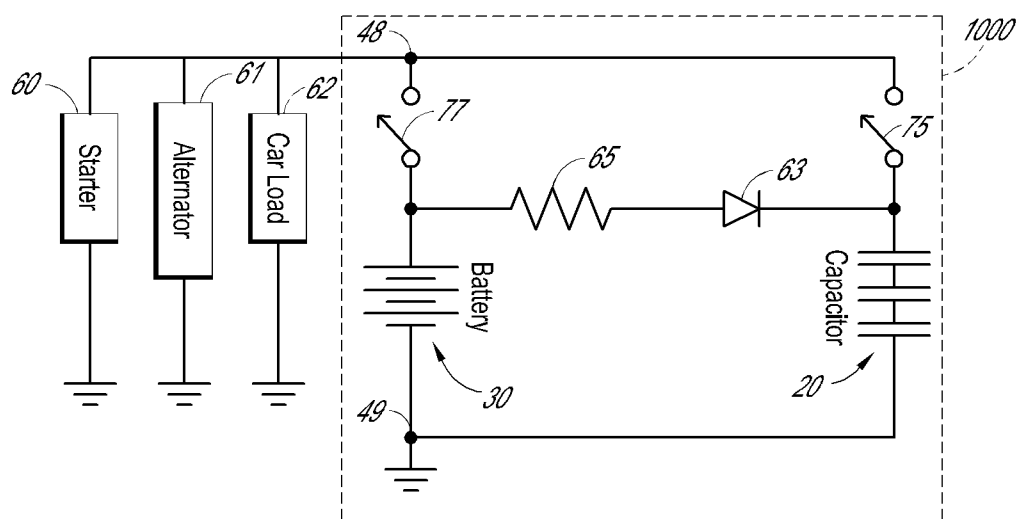


FIG. 14B

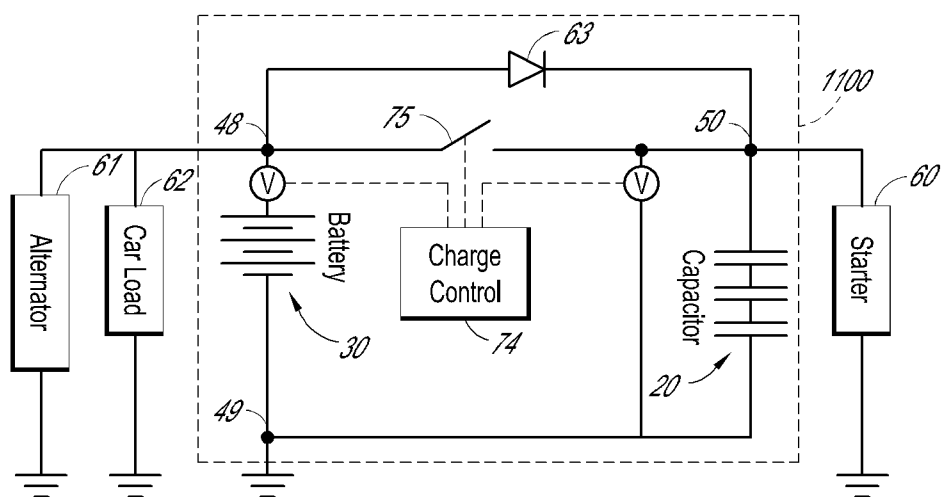


FIG. 15

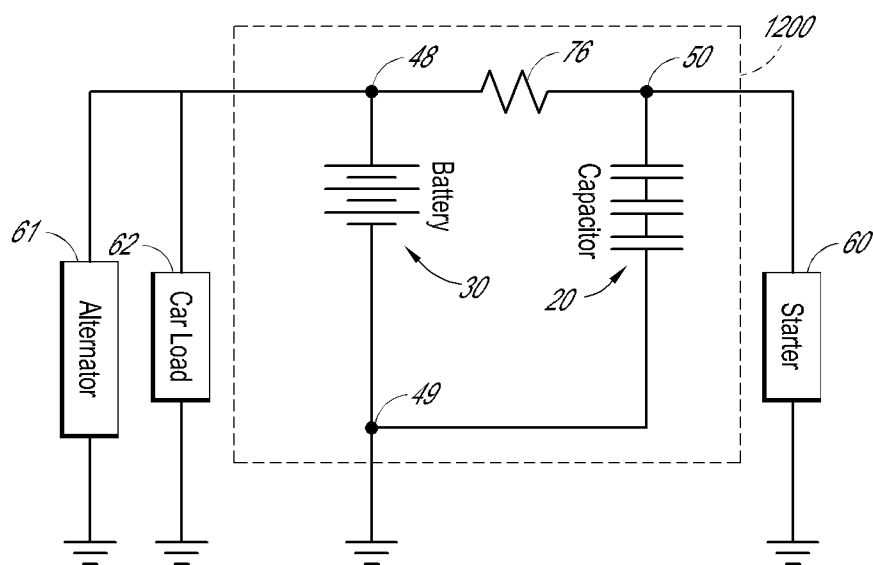


FIG. 16

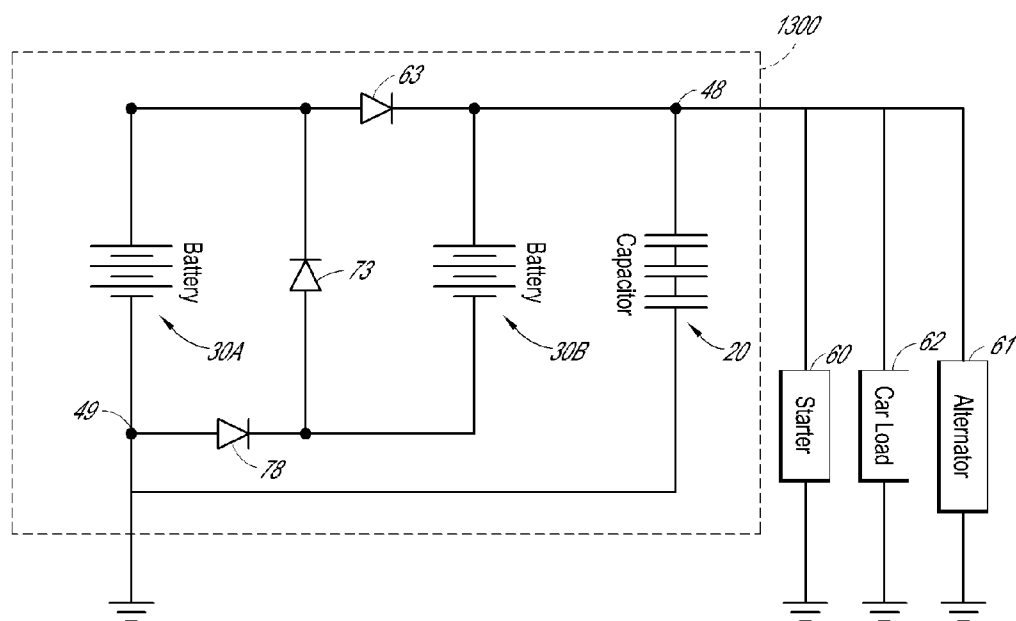


FIG. 17

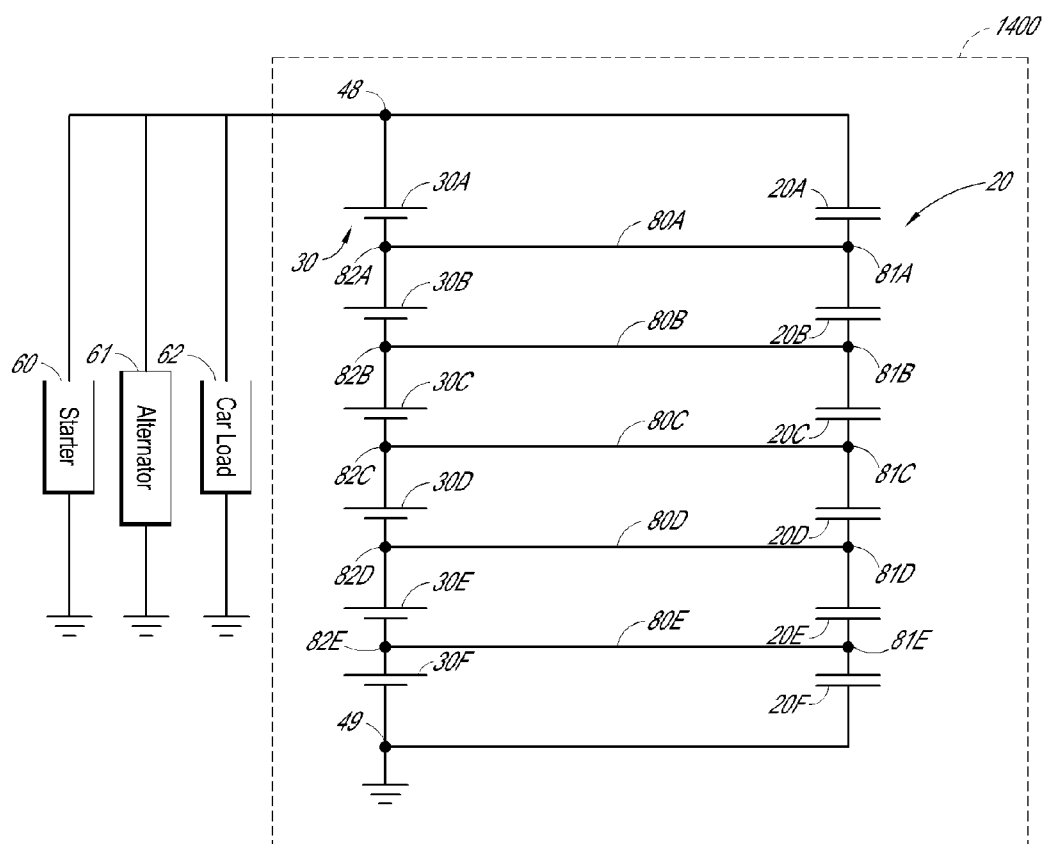


FIG. 18

ULTRACAPACITOR/BATTERY COMBINATION AND BUS BAR SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/610,425 filed Mar. 13, 2012 entitled “COMBINATION BATTERY AND ELECTRIC DOUBLE LAYER CAPACITOR,” U.S. Provisional Patent Application No. 61/610,417 filed Mar. 13, 2012 entitled “ULTRACAPACITOR AND BATTERY COMBINATION WITH SWITCHED POWER MANAGEMENT SYSTEM” and U.S. Provisional Patent Application No. 61/610,399 filed Mar. 13, 2012 entitled “CAPACITOR AND BATTERY COMBINATION WITH VOLTAGE MANAGEMENT SYSTEM.” The disclosures of these prior applications are considered part of, and are incorporated by reference in, this disclosure in its entirety.

BACKGROUND

[0002] 1. Field

[0003] The present disclosure relates generally to a combined capacitor and battery combination, and related methods of making and using such combinations.

[0004] 2. Description of the Related Art

[0005] Many different types of energy storage systems, such as systems including batteries or capacitors, are known. Such conventional energy storage systems may be implemented to provide power to other devices, such as a starter in a vehicle.

[0006] Conventional vehicle batteries have several limitations. One limitation is that a battery may have limited cycle efficiency, and thus may experience decreased recharge performance, or even completely lose its ability to charge after a given number of charge/discharge cycles. For example, the cycle efficiency of a battery may decrease when used in a vehicle that starts and stops the engine repeatedly, such as in a hybrid vehicle that engages a starter regularly to adjust from electric to gas power. The cycle efficiency of a battery may also be affected under some temperature conditions, as described further below. It will be understood that while reference is made herein to hybrid vehicles and vehicles with an internal combustion engine, embodiments described herein may be employed within other vehicle or non-vehicle systems.

[0007] Batteries are rated using several different measurements. For example, Cold Cranking Amps (“CCA”) is a rating used in the battery industry to define a battery’s ability to start an engine in cold temperatures. The rating is the number of amps a new, fully charged battery can deliver at 0° F. for 30 seconds, while maintaining a voltage of at least 7.2 volts, for a 12 volt battery. The higher the CCA rating, the greater the starting power of the battery.

[0008] The term “CA” means Cranking Amps, and is used to describe the discharge load in amperes which a new, fully charged battery at 32° F. (0° C.), can continuously deliver for 30 seconds and maintain a terminal voltage equal or greater than 1.2 volts per cell. It is sometimes referred to as Marine Cranking Amps. In addition, the term Reserve Capacity (“RC”) is a term used to define the ability of a battery to power a vehicle with an inoperative alternator or fan belt. The rating is the number of minutes a battery at 80° F. can be discharged at 25 amps and maintain a voltage of 10.5 volts for a 12 volt

battery. The higher the reserve rating, the longer a vehicle can operate should the alternator or fan belt fail.

SUMMARY

[0009] The systems, methods and devices of this disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

[0010] One innovative aspect of the subject matter described in this disclosure can be implemented in an energy storage device. The energy storage device includes an energy storage device housing. The energy storage device housing includes a battery housing portion, a capacitor housing portion, and a housing lid configured to cover the battery housing portion and the capacitor housing portion. The energy storage device includes a battery disposed within the battery housing portion. The battery includes a first battery terminal extending through a battery lid enclosing the battery housing portion. The energy storage device includes a capacitor disposed within the capacitor housing portion and connected in parallel with the battery. The capacitor includes a first capacitor terminal. The energy storage device includes a first bus bar electrically connecting the first battery terminal and the first capacitor terminal. The energy storage device includes a first external device terminal extending through the energy storage device housing and configured to electrically connect to the first battery terminal and the bus bar.

[0011] In another innovative aspect, the first external device terminal comprises a stud configured to extend through an opening in the housing lid, through an opening in the first bus bar, and into a first opening in the battery terminal.

[0012] In another innovative aspect, the battery housing portion and capacitor housing portion are horizontally adjacent with respect to each other.

[0013] In another innovative aspect, the first bus bar extends across a portion of the battery lid, and between the battery lid and the housing lid, to the first capacitor terminal.

[0014] Another innovative aspect of the subject matter described in this disclosure can be implemented in a method of manufacturing a combined battery/capacitor energy storage device. The method includes providing an energy storage device housing comprising a battery housing portion, a capacitor housing portion, and a housing lid configured to cover the battery housing portion and the capacitor housing portion. The method includes providing a battery within the battery housing portion. The battery includes a first battery terminal extending through a battery lid enclosing the battery housing portion. The method includes inserting a capacitor into the capacitor housing portion. The capacitor includes a first capacitor terminal. The method includes connecting a first bus bar to the first battery terminal and the first capacitor terminal. The method includes extending a first external device terminal through the energy storage device housing. The method includes electrically connecting the first external device terminal to the first battery terminal and the bus bar.

[0015] Details of one or more implementations of the subject matter described in this disclosure are set forth in the accompanying drawings and the description below. Although the examples provided in this disclosure are primarily described in terms of a vehicle system, the concepts provided herein may apply to other types of systems with or within which an energy storage system is implemented. Other features, aspects, and advantages will become apparent from the

description, the drawings and the claims. Note that the relative dimensions of the following figures may not be drawn to scale.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 illustrates an embodiment of a capacitor/battery combination energy storage device.

[0017] FIG. 2A is a front perspective cross-sectional cutaway and exploded view of an embodiment of a two-terminal capacitor/battery combination energy storage device.

[0018] FIG. 2B is a left perspective view of a capacitor bank that can be implemented within a capacitor/battery combination energy storage device.

[0019] FIG. 3 is a front perspective cross-sectional cutaway view of an embodiment of a three-terminal capacitor/battery combination energy storage device.

[0020] FIG. 4 is a front perspective exploded view of an embodiment of a capacitor/battery combination energy storage device.

[0021] FIG. 5 is a front perspective exploded view of another embodiment of a capacitor/battery combination energy storage device.

[0022] FIG. 6A is a side cross-sectional view of an embodiment of a terminal and bus-bar that can be implemented within a capacitor/battery combination energy storage device.

[0023] FIG. 6B is an exploded side cross-sectional view of the terminal and bus-bar embodiment shown in FIG. 6A.

[0024] FIG. 7 is a side view of an embodiment of a capacitor/battery combination energy storage device with a flexible bus bar.

[0025] FIG. 8 is a schematic diagram illustrating an embodiment of a capacitor/battery combination energy storage device with two external terminals.

[0026] FIG. 9 is a schematic diagram illustrating an embodiment of a capacitor/battery combination energy storage device with three external terminals and a rectifier.

[0027] FIG. 10 is a schematic diagram illustrating an embodiment of the capacitor/battery combination energy storage device shown in FIG. 9, with a current limiter in series with the rectifier.

[0028] FIG. 11 is a schematic diagram illustrating another embodiment of a capacitor/battery combination energy storage device, with a DC/DC converter.

[0029] FIG. 12 is a schematic diagram illustrating another embodiment of a capacitor/battery combination energy storage device, with an embodiment of the DC/DC converter shown in FIG. 11.

[0030] FIG. 13 is a schematic diagram illustrating another embodiment of the capacitor/battery combination energy storage device of FIG. 12, with the DC/DC converter in parallel with the main rectifier.

[0031] FIG. 14A is a schematic diagram illustrating an embodiment of a two-terminal capacitor/battery combination energy storage device with two switches.

[0032] FIG. 14B is a schematic diagram illustrating another embodiment of a two-terminal capacitor/battery combination energy storage device with two switches.

[0033] FIG. 15 is a schematic diagram illustrating an embodiment of a three-terminal capacitor/battery combination energy storage device with one switch.

[0034] FIG. 16 is a schematic diagram illustrating an embodiment of a three-terminal capacitor/battery combination energy storage device with a current limiter between two of the terminals.

[0035] FIG. 17 is a schematic diagram illustrating an embodiment of a three-terminal capacitor/battery combination energy storage device with a network of rectifiers.

[0036] FIG. 18 is a schematic diagram illustrating another embodiment of a two-terminal capacitor/battery combination energy storage device with a capacitor bank and a battery bank.

[0037] Like reference numbers and designations in the various drawings indicate like elements.

DESCRIPTION

[0038] Some embodiments of the invention relate to systems and methods of providing a combination energy storage device that includes a battery system in combination with a capacitor system. In some embodiments, the battery system may have one or more batteries and the capacitor system may have one or more capacitors. The capacitors may be based on various technologies, such as an ultracapacitor, also known as a supercapacitor or electric double-layer capacitor. Examples of ultracapacitors can be found, for example, in U.S. Pat. Nos. 7,791,860; 7,352,558; 7,342,770; 8,072,734; and 7,508,651. Examples of combined battery and ultracapacitor devices can be found, for example, in U.S. Patent Application Publication No. 2012/0237799, which is considered part of, and is incorporated by reference in, this disclosure in its entirety. It will be understood that while reference is made herein to an "EDLC" (electric double layer capacitor), or ultracapacitor, the embodiments described herein can be implemented with other types of capacitors, and should not be limited to EDLCs or ultracapacitors.

[0039] In one embodiment, the combined energy storage device includes a battery and a capacitor in a single, integrated package. In some embodiments, a symmetric capacitor, in which a similar material is used for both electrodes, may be employed. In some embodiments, an asymmetric capacitor, in which different materials are used for the two electrodes, may be employed. In another embodiment, the combined energy storage device includes a single, integrated package that is of similar size to the standard vehicle non-hybrid batteries available on the open market ("OEM" batteries).

[0040] Unless otherwise specified, the singular or plural form of a "capacitor" and "battery" as described herein can refer to a single capacitor or battery, respectively, or a plurality of capacitors or batteries, respectively, as in a capacitor bank or battery bank connected in series or in parallel. Implementing a capacitor in combination with a battery in a combined battery/capacitor energy storage device can help reduce or mitigate one or more of the aforementioned limitations of an energy storage system that includes only a battery for energy storage.

[0041] For example, a capacitor generally can sustain an increased number of discharge/charge cycles, and thus has a longer cycle life, than a comparable battery. A combined energy storage device that uses a capacitor in combination with a battery may thus provide improved cycle life, and may provide benefits to an application with increased charge/discharge cycles, such as a start/stop application.

[0042] A capacitor generally may also provide a more efficient delivery of power, and a quicker charge and discharge

time than a comparable battery. Such improved capacitor efficiency may result from the generally more efficient charge acceptance, higher discharge rate and faster chemical kinetics, of a capacitor relative to a comparable battery. A capacitor may also have a lower equivalent series resistance (ESR) than the resistance of a comparable battery. Thus, as described herein, a capacitor generally does not experience the aforementioned drop in voltage as a battery may, when a power supply, such as an alternator stops charging. Similarly, a capacitor also has a reduced tendency to “cycle down” over time with respect to that of a battery. A capacitor used in combination with a battery was found to reduce the peak current stress experienced by the battery during use.

[0043] A capacitor may also generally be less susceptible to some temperature effects than a battery. For example, a capacitor can sustain a charge and/or retain higher voltages at lower temperatures, and thus can deliver higher power, than a comparable battery at the same temperature, or a comparable capacitor at a higher temperature. Such aspects of a capacitor were found to provide improved performance, for example, of a vehicle ignition system when the capacitor was used to provide power to a starter.

[0044] Additionally, when a capacitor is disconnected from an alternator or other power source, it has higher output voltage, or open circuit voltage, and exhibits lower voltage drop under load than a comparable battery under similar conditions. Such decreased voltage drop of a capacitor can also translate into increased cranking power, and thus a faster crank speed of a vehicle starter, when the capacitor is employed within a vehicle energy storage system. The aforementioned improvements in the voltage drop of a capacitor may be enhanced at lower temperature conditions.

[0045] Additionally, a capacitor used in combination with a battery in an energy storage device was found to provide a reserve or backup energy source in the event of reduced battery performance or failure (for example, to provide emergency lighting power, starter, or alternator power).

[0046] One embodiment is a battery and ultracapacitor combination in a combined energy storage device. The battery and ultracapacitor can be packaged together in a combination device in a number of different ways. For example, some embodiments include a combined battery/capacitor storage device that forms a battery system for a “drop-in” replacement for one or more batteries in a vehicular battery system, such as a Battery Council International (BCI) Group 31 battery. Of course, one of ordinary skill in the art could use teachings of the present disclosure to create combined capacitor/battery systems that are designed to meet other OEM sizes and standards, such as those in the BCI Groups, as described further below. As such, some embodiments include a combined battery/capacitor storage device that has a housing of substantially the same dimensions, mounting features and/or terminals of similar positioning and/or size, and/or similar output ratings, as an OEM battery. For example, in some embodiments, the battery and ultracapacitor are selected to provide output of 6 or 12 volts, and the standard form factor conforms to a corresponding 6 or 12 volt battery. In some embodiments, the standard form factor conforms to a standard for a lead-acid battery. In some embodiments, output of the battery and ultracapacitor and a form factor of the enclosure conform to a standard voltage rating and a standard form factor to permit retrofitting of a battery that comprises one or more conventional storage cells without an ultracapacitor. Some embodiments include methods for making such a bat-

tery system, comprising, in an enclosure that conforms to a standard form factor, disposing a battery and at least one ultracapacitor coupled to the battery to provide electrical energy via battery terminals external to the combined hybrid energy storage device. Some embodiments include providing an assembly of the energy storage device described herein, with at least one adapter that adapts the enclosure for mounting in place of a standard form factor for a battery that comprises one or more conventional storage cells without an ultracapacitor. The enclosure can be smaller than the standard form factor for the battery in the place of which it is to be mounted, or can be differently shaped than the standard form factor for the battery in the place of which it is to be mounted.

[0047] Also described herein are embodiments of a combined battery capacitor device with various electrical components and configurations to provide improved performance and control to the combined battery capacitor device.

Battery/Capacitor Combination

[0048] FIG. 1 illustrates an embodiment of a hybrid capacitor/battery combination energy storage device **10**. Hybrid device **10** can include an enclosure or housing **12** forming an interior cavity into which one or more capacitors **20** (e.g., EDLCs) and a battery **30** can be placed. Housing **12** can comprise sidewalls **11**, a lid **13**, and a base **15** to form its interior cavity. Lid **13** can be permanently or removably attached to the remainder of housing **12**. External device terminals **48** and **49** can be attached to lid **13** and be configured to connect device **10** to an external system. The device terminals **48** and **49** can be sized and shaped to correspond to an external battery terminal for a standard form factor battery. In some embodiments, the device **10** can include a third device terminal, to provide additional functionality, as described in some of the embodiments herein. The terminals can extend from at least one of a top, front and side location on the housing **12**.

[0049] The device **10** can be sized with a height H, width W and depth D to conform to a standard OEM battery, such as any one or more of the BCI Group sizes listed in the following Table 1:

TABLE 1

BCI Group Number	Typical Maximum Overall Dimensions					
	Millimeters			Inches		
	W	D	H	W	D	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 ³ / ₁₆
22HF	241	175	229	9 ¹ / ₂	6 ⁷ / ₈	9
22NF	240	140	227	9 ¹ / ₁₆	5 ¹ / ₂	8 ¹³ / ₁₆
22R	229	175	211	9	6 ⁷ / ₈	8 ³ / 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 ¹³ / ₁₆
27H	298	173	235	11 ³ / ₄	6 ¹³ / ₁₆	9 ¹ / ₄

TABLE 1-continued

BCI Group Number	Typical Maximum Overall Dimensions					
	Millimeters			Inches		
	W	D	H	W	D	H
29NF	330	140	227	13	5½	8½ ¹⁵ / ₁₆
33	338	173	238	13½ ¹⁶ / ₁₆	6½ ¹³ / ₁₆	9¾
34	260	173	200	10¼	6½ ¹³ / ₁₆	7⅞
34R	260	173	200	10¼	6½ ¹³ / ₁₆	7⅞
35	230	175	225	9¼ ¹⁶ / ₁₆	6⅞	8⅞
36R	263	183	206	10⅝	7¼	8⅞
40R	277	175	175	10½ ¹⁵ / ₁₆	6⅞	6⅞
41	293	175	175	11¾ ¹⁶ / ₁₆	6⅞	6⅞
42	243	173	173	9½ ¹⁶ / ₁₆	6½ ¹³ / ₁₆	6½ ¹³ / ₁₆
43	334	175	205	13⅞	6⅞	8¼ ¹⁶ / ₁₆
45	240	140	227	9⅞ ¹⁶ / ₁₆	5½	8½ ¹⁵ / ₁₆
46	273	173	229	10¾	6½ ¹³ / ₁₆	9
47	246	175	190	9½ ¹⁶ / ₁₆	6⅞	7½
48	306	175	192	12¼ ¹⁶ / ₁₆	6⅞	7¾ ¹⁶ / ₁₆
49	381	175	192	15	6⅞	7¾ ¹⁶ / ₁₆
50	343	127	254	13½	5	10
51	238	129	223	9¾	5¼ ¹⁶ / ₁₆	8½ ¹³ / ₁₆
51R	238	129	223	9¾	5¼ ¹⁶ / ₁₆	8½ ¹³ / ₁₆
52	186	147	210	7½ ¹⁶ / ₁₆	5½ ¹³ / ₁₆	8¼
53	330	119	210	13	4¼ ¹⁶ / ₁₆	8¼
54	186	154	212	7½ ¹⁶ / ₁₆	6¼ ¹⁶ / ₁₆	8¾
55	218	154	212	8¾	6¼ ¹⁶ / ₁₆	8¾
56	254	154	212	10	6¼ ¹⁶ / ₁₆	8¾
57	205	183	177	8¼ ¹⁶ / ₁₆	7¾ ¹⁶ / ₁₆	6½ ¹⁵ / ₁₆
58	255	183	177	10¼ ¹⁶ / ₁₆	7¾ ¹⁶ / ₁₆	6½ ¹⁵ / ₁₆
58R	255	183	177	10¼ ¹⁶ / ₁₆	7¾ ¹⁶ / ₁₆	6½ ¹⁵ / ₁₆
59	255	193	196	10¼ ¹⁶ / ₁₆	7¾	7¾
60	332	160	225	13¼ ¹⁶ / ₁₆	6¾ ¹⁶ / ₁₆	8¾
61	192	162	225	7¾ ¹⁶ / ₁₆	6¾	8¾
62	225	162	225	8¾	6¾	8¾
63	258	162	225	10¾ ¹⁶ / ₁₆	6¾	8¾
64	296	162	225	11¼ ¹⁶ / ₁₆	6¾	8¾
65	306	190	192	12¼ ¹⁶ / ₁₆	7½	7¾ ¹⁶ / ₁₆
70	208	179	196	8¾ ¹⁶ / ₁₆	7¼ ¹⁶ / ₁₆	7¼ ¹⁶ / ₁₆
71	208	179	216	8¾ ¹⁶ / ₁₆	7¼ ¹⁶ / ₁₆	8½
72	230	179	210	9¼ ¹⁶ / ₁₆	7¼ ¹⁶ / ₁₆	8¼
73	230	179	216	9¼ ¹⁶ / ₁₆	7¼ ¹⁶ / ₁₆	8½
74	260	184	222	10¼	7¼	8¾
75	230	179	196	9¼ ¹⁶ / ₁₆	7¼ ¹⁶ / ₁₆	7¼ ¹⁶ / ₁₆
76	334	179	216	13¾	7¼ ¹⁶ / ₁₆	8½
78	260	179	196	10¼	7¼ ¹⁶ / ₁₆	7¼ ¹⁶ / ₁₆
85	230	173	203	9¼ ¹⁶ / ₁₆	6½ ¹³ / ₁₆	8
86	230	173	203	9¼ ¹⁶ / ₁₆	6½ ¹³ / ₁₆	8
90	246	175	175	9¼ ¹⁶ / ₁₆	6⅞	6⅞
91	280	175	175	11	6⅞	6⅞
92	317	175	175	12½	6⅞	6⅞
93	354	175	175	15	6⅞	6⅞
95R	394	175	190	15¾ ¹⁶ / ₁₆	6⅞	7½
96R	242	173	175	9¾ ¹⁶ / ₁₆	6½ ¹³ / ₁₆	6⅞
97R	252	175	190	9½ ¹⁶ / ₁₆	6⅞	7½
98R	283	175	190	1½ ¹⁶ / ₁₆	6⅞	7½
PASSENGER CAR AND LIGHT COMMERCIAL BATTERIES 6-VOLT(3 CELLS)						
1	232	181	238	9⅞	7⅞	9¾
2	264	181	238	10¾	7⅞	9¾
2E	492	105	232	19¾ ¹⁶ / ₁₆	4⅞	9¾
2N	254	141	227	10	5¾ ¹⁶ / ₁₆	8½ ¹⁵ / ₁₆
17HF	187	175	229	7¾	6⅞	9
HEAVY-DUTY COMMERCIAL BATTERIES 12-VOLT (6 CELLS)						
4D	527	222	250	20¾	8¾	9⅞
6D	527	254	260	20¾	10	10¼
8D	527	283	250	20¾	11⅞	9⅞
28	261	173	240	10¾ ¹⁶ / ₁₆	6½ ¹³ / ₁₆	9¼ ¹⁶ / ₁₆
29H	334	171	232	13¾	6¾	9¾ 10
30H	343	173	235	13½	6½ ¹³ / ₁₆	9¼ 10
31	330	173	240	13	6½ ¹³ / ₁₆	9¼ ¹⁶ / ₁₆

TABLE 1-continued

BCI Group Number	Typical Maximum Overall Dimensions					
	Millimeters			Inches		
	W	D	H	W	D	H
ELECTRIC VEHICLE BATTERIES 6-VOLT (3CELLS)						
GC2	264	183	270	10¾	7¾ ¹⁶ / ₁₆	10¾
GC2H	264	183	295	10¾	7¾ ¹⁶ / ₁₆	11¾

[0050] The approximate maximum heights listed in Table 1 include the terminal posts. Width and length measurements are generally to the widest point, including protruding flanges, except for hold-down flanges at the bottom of the battery. It will be understood that other OEM sizes can be implemented, including BCI Group sizes not listed, such as Heavy-Duty Motor Coach, Bus, and Special Tractor Batteries.

[0051] Referring again to FIG. 1, the EDLC 20 can include electrodes and electrolyte contained within a housing 22 of each EDLC, as is known in the art. A plurality of the EDLCs 20 can be electrically connected in series or in parallel to form a capacitor bank. The battery 30 can include a housing 32 with an interior battery cavity configured to contain battery plates, electrolyte and other components, as is known in the art. Housing 32 of the battery 30 can include a lid 33, base 35, and sidewalls 31 to form its interior cavity. The battery 30 can be a standard OEM battery, such as a BCI Group size. The embodiment in FIG. 1 may include additional packaging material and structure, as it includes the housings 22, 32 for the EDLCs 20 and battery 30, respectively, and the housing 12 for the overall hybrid device 10.

[0052] Some embodiments herein integrate existing internal parts of a battery, such as the plates, electrolyte, etc., into a housing configured to receive both the battery and the EDLC pack, to provide the combination energy storage device. Such embodiments reduce the number of parts and manufacturing costs related to such a device. Additionally, some embodiments allow a device with increased battery and/or capacitor charge capacity to be fit into a similar space as an embodiment of a device that uses both prepackaged capacitors and batteries within an additional external package. For example, in one embodiment, a 42 amp-hour rated device with an integrated package that houses internal battery components and an ELDC pack was fit within a comparable space envelope of a 30 amp-hour rated device with prepackaged capacitors and batteries enclosed within an additional housing. An integrated battery housing also provides improved heat transfer and thermal dissipation from the battery, as there is no insulating layer between an internal battery compartment and external combination energy storage device housing.

EDLC Pack at the Side of Battery

[0053] FIG. 2A is a front perspective cross-sectional cut-away and exploded view of an embodiment of an integrated capacitor/battery device 100. Device 100 can include a battery 130 and capacitor 120, and be similar to device 10, battery 30 and capacitor 20 in FIG. 1. The capacitor 120 can comprise a capacitor bank including a plurality of capacitor cells 120A-120F, positioned in parallel or series. The number of capacitor cells 120A-120F can vary, and six are shown for

illustrative purposes. The electrical connections between capacitor cells 120A-120F and the other components of device 100 are described further below with reference to FIGS. 2B, 6A and 6B.

[0054] Continuing to refer to FIG. 2A, the device 100 can include a device housing 112 comprising one or more sidewalls 111A-111D, a base 115, and a lid 113. The device housing 112 can include a battery housing portion 114 with an interior battery cavity 116 configured to contain a battery, or portions of a battery. For example, the battery housing portion can be configured to receive a packaged battery 30, such as an OEM battery, including its external housing 32, similar to the device housing 12 shown in FIG. 1. As such, a discrete battery can be contained within battery housing portion.

[0055] In some embodiments, the device housing 112 can form an integrated battery housing 114, to receive an integrated battery. For example, the interior battery cavity 116 can be configured to receive the internals of a battery, such as one or more battery electrodes, battery cell terminals and other electrical connections, electrolyte, etc. (not shown), but without requiring the entire external battery housing 32 and the entire external housing 12 of the hybrid device 10 (FIG. 1). For example, interior battery cavity 116 can be formed from a portion of sidewalls 111A-111C, a portion of a base 115, a battery lid 133, and an inner sidewall 117 extending between 111B and 111D.

[0056] In some embodiments, the interior cavity 116 can be separated into a plurality of sub-cavities 116A, through a series of partitions 119 within the battery housing portion 114. Each sub-cavity 116A can house a battery electrode, to form one or more individual battery cells within cavity 116. Each battery cell can include a positive and negative battery cell terminal (not shown). These battery cell terminals can be electrically connected together in a manner similar to a known, discrete OEM battery, and placed in electrical communication with internal battery terminals 41 and 42 extending through the lid 133. The “internal battery terminals” can be defined as the external terminals for a discrete battery placed within the energy storage device housing, or the battery terminals of an integrated battery formed within the integrated battery housing, as described further herein.

[0057] Embodiments of device 100 with the integrated battery housing 114 shown in FIG. 2A may eliminate the need for one or more sidewalls 31 and base 35 of the battery housing 32 shown in FIG. 1. As such, device 100 can allow battery 130 to be integrated directly within the device housing 112 of hybrid energy storage device 100, without requiring an entire, additional, separate external battery housing. Referring again to FIG. 2A, in some embodiments, all or a portion of the integrated device housing 112 of device 100 can comprise an integrally-formed, unitary component. In some embodiments, the sidewalls 111A-111D, base 115 and inner sidewall 117 can be an integrally formed unitary component, for example, through a molding or other suitable process.

[0058] The device housing 112 can be divided into a capacitor housing portion 124 with an interior capacitor cavity 126 configured to contain capacitors 120A-120F. The capacitor housing portion 124 can be positioned horizontally adjacent to the battery housing portion 114. In use, the internal battery components can be loaded into the interior cavity 116 of battery housing portion 114 and connected to the aforementioned battery cell terminals, which can be connected to form the internal battery terminals, and covered or sealed with battery lid 133. The capacitor housing portion 124

can be loaded with the capacitors 120-120F, and electrical connections made between the capacitors 120A-120F and battery 130, as described further below. The device housing 112 can be closed or sealed with the device cover 113. In some embodiments, the battery lid 133 can be omitted, and the device cover 113 can be used to cover both the battery housing portion 114 and the capacitor housing portion 124.

[0059] The capacitor cavity 126 can be formed from a portion of the three sidewalls 111A, 111B, and 111D, a portion of the base 115, inner sidewall 117, and the lid 113. As such, sidewalls 111A, 111B, and 111D, base 115, and inner sidewall 117 can form both a part of the battery housing portion 114 and the capacitor housing portion 124. As such, capacitor housing portion 124 and the battery housing portion 114 can share one or more common walls. In some embodiments, the inner sidewall 117 can be positioned between the capacitor 120 and the inner components of battery 130, without additional intervening walls. In some embodiments, the battery 130 can be formed within portions of the one or more of the sidewalls 111 and/or base 115, without intervening structure between these and the internal battery components.

[0060] Embodiments of device housing 112 that include one or more of these common walls forming both battery housing portion 114 and capacitor housing portion 124, without additional intervening, redundant walls, can decrease the overall space envelope of the device 100. Additionally, the battery and/or capacitor charge capacity for device 100 can be increased, and the heat transfer and thermal dissipation from the battery 130 within device 100 can be increased, for a given space envelope. Such benefits can be beneficial, for example, when hybrid device 100 is configured to fit within the predetermined space envelope of a standard OEM battery.

[0061] The capacitor housing portion 124 of the device 100 can be sized and shaped to house capacitors of various quantities, sizes, shapes and/or orientations, and may be sized and shaped to house capacitors of more than one size, or shape, or orientation. For example, the capacitor housing portion 124 may be expandable, and/or may be sized to include extra room to allow for expansion of capacitor capacity. The housing portion 124 shown in FIG. 2A can be configured to extend horizontally or vertically with respect to the view shown, or tangentially (into/out of the plane of the view shown). Additionally, although the capacitors 120A-120F are shown in an approximately horizontal orientation in FIG. 2A, the EDLCs can be oriented vertically, horizontally, tangentially, in one or more rows or columns, or combinations thereof.

[0062] FIG. 3 is a front perspective cross-sectional cutaway view of a three-terminal embodiment of an integrated capacitor/battery device 200. Device 200 can be similar to device 100 shown in FIG. 3, but with a third device terminal 50 to provide additional functionality. Further details regarding the functionality of device 200, and the wiring, terminal and bus bar configurations shown in FIGS. 2 and 3A are provided below.

EDLC Pack on Top of the Battery

[0063] FIGS. 4 and 5 are front perspective exploded views of embodiments of a combination capacitor/battery device 100A, 100B, respectively. The embodiments shown in FIGS. 4 and 5 can be similar to those in FIGS. 2A-3, with one or more of the following differences.

[0064] In the embodiments shown in FIGS. 4 and 5, the a battery housing portion 214 can be configured to be vertically adjacent to (either above or below) a capacitor housing por-

tion 224. For illustrative purposes, the battery housing portion 214 is positioned below the capacitor housing portion 224, such that the battery 230 can be positioned below the capacitor 220. A lid 213 can be configured to cover and/or seal the capacitor housing portion 224, to enclose the capacitor 20 therein.

[0065] A separator lid 234 can be positioned between the battery housing portion 214 and the capacitor housing portion 224. The separator lid 234 can be configured to provide a dual function of both the battery lid 133 and inner sidewall 117 described above (FIGS. 2A-3). For example, the separator lid 234 can be configured to both cover the inner cavity 216 of battery housing portion 214, and to separate the battery housing portion 214 from capacitor housing portion 224. Separator lid 234 can at least partially seal the battery housing portion 214. For example, the separator lid 234 may sufficiently seal the battery internals within battery housing portion 214 to prevent or reduce leakage, while still allowing partial venting therefrom. The separator lid 234 can be removable or permanently attached to the battery housing portion while providing such sealing function. Such embodiments can reduce the need for both the battery lid 133, and the sidewall 117 between the battery housing portion 14 and capacitor housing portion 124 (FIGS. 2A-3). By integrating the functionality of a battery lid and a separator between battery and capacitor compartments 214, 224, respectively, embodiments of devices 100A, 100B that include the separator lid 234 can further increase battery and/or capacitor charge capacity, and improve heat transfer and thermal dissipation from the battery, for a given space envelope.

[0066] Continuing to refer to FIGS. 4 and 5, the sidewalls 211 of device housing 212 may include battery portion sidewalls 111A that form a portion of battery housing portion 214, and capacitor portion sidewalls 111B that form a portion of capacitor housing portion 224. The sidewalls 111A, 111B can be configured in a number of different ways. For example, the sidewalls 111B can be attached to and extend upwardly from separator lid 234. In some embodiments, sidewalls 111A can extend upwardly from the sidewalls 111B, with the separator lid 234 configured to be inserted within a perimeter formed within sidewalls 111B. In some embodiments, sidewalls 111B can extend downwardly from the lid 213 to form the capacitor housing portion 224 and enclose the capacitor 120. The sidewalls 111B can be configured as a separate section that can form the capacitor housing portion 224, with lid 213 being a separate component. Thus, the device housing and its various portions described herein can be separately or integrally formed in a variety of methods.

[0067] The embodiment shown in FIGS. 4 and 5 may have improved weight distribution for handling etc., as the battery, which can generally be denser, and thus, heavier than the EDLC, is distributed approximately evenly across the width of the overall device 10. In some embodiments, the battery is positioned below the capacitor, to prevent toppling of the device, which further improves weight distribution and handling.

[0068] In an embodiment of the combined battery/capacitor storage device shown in FIGS. 4 and 5, a Group 75/25 Battery (12V) with dimensions of 9.3 inch (L)×6.8 inch (W)×7.0 inch (H) can be employed. The integrated battery can be configured to occupy approximately the lower ⅔ of the container. In this embodiment, the capacitors can occupy an estimated remaining 9.0 inch (L)×6.5 inch (W)×2.3 (H) inch of volume within the capacitor housing portion. It will be

understood that this embodiment is not to be limited to a Group 75/25 Battery, or the voltages and dimensions described, and is merely for illustrative purposes.

Terminals/Bus Bars

[0069] FIGS. 6A and 6B are a side cross-sectional and an exploded side cross-sectional view, respectively, illustrating embodiments of electrical connections, terminal and bus-bar configurations that can be implemented within a combined battery/capacitor storage device, such as those shown in FIGS. 2A and 3. FIG. 2B is a left perspective view of a capacitor bank that can be implemented within a capacitor/battery combination energy storage device, such as devices 100 and 200 from FIGS. 2A and 3.

[0070] For illustrative purposes, the embodiments of FIGS. 2A, 3, 6A and 6B are shown in the context of a side-by-side or horizontally adjacent combined battery/capacitor device. However, it will be understood that similar features can be employed for the terminal and bus-bar configuration of an over-under or vertically adjacent combined battery/capacitor device, such as those described herein and shown in FIGS. 4 and 5. Additionally, the embodiments shown can be employed for the bus-bar configuration of an energy storage device with an integrated battery or a discrete battery.

[0071] Referring to FIGS. 2A and 2B, capacitors 120A-120F can each include capacitor terminals 123A and 123B, which can be connected in series or parallel with respect to each other to form capacitor bank 120. The terminals 123A and 123B can be connected with a plurality of capacitor interconnects, bus bars, etc. In the illustrated embodiment, capacitor interconnects 121A-121E extend between and electrically connect the terminals 123A, 123B of adjacent capacitors in bank 120. For example, the interconnect 121A (FIG. 2A) can connect a terminal 123A of capacitor 120A with a terminal 123B of capacitor 120C, and so forth. In the illustrated embodiment, capacitors 120A-120F are connected in series with interconnects 121A-121E, such that terminal 123B of capacitor 120A forms a first capacitor bank terminal 125 and terminal 123A of capacitor 120B forms a second capacitor bank terminal 127.

[0072] Referring to FIGS. 2A and 2B, the combined battery/capacitor device 100 can be configured as a two-terminal device, comprising two internal battery terminals 41 and 42. The battery terminals 41, 42 can include one or more openings 43 extending through each terminal. The openings 43 can comprise a bushing or a threaded opening. In some embodiments, the battery terminals 41, 42 can be insert-molded into the battery lid 33. The internal battery components can include an internal terminal post configured to engage with the opening 43. The internal terminal post can comprise any suitable terminal material, such as lead. The internal terminal post can engage with the opening 43 in various ways, such as by induction welding. The internal threads on the battery terminals 41, 42 can be used to connect the battery to the capacitor bank 120, as well as an external terminal to the combined energy storage device, as described further below.

[0073] In the illustrated embodiment, the first battery terminal 41 can be connected with a first bus bar 44 to the first capacitor bank terminal 125 of the capacitor bank 120. The first bus bar 44 can be any of a number of shapes; in the illustrated embodiment, it comprises a downwardly extending portion 44A that extends along a side of battery 130 and connects the battery terminal 41 with the capacitor terminal

125 (FIG. 2B). An upwardly extending portion **44B** can extend along the side of battery **130**, with a laterally extending portion **44C** extending from portion **44B** to the first external device terminal **48**. The first external device terminal **48** can extend from the first bus bar **44**, to connect the device **100** to an external system at a first point, such as a connection to a vehicle's electrical system (see, e.g., FIGS. 3A; 6A-6B; 8-18).

[0074] Referring again to FIGS. 2A and 2B, the second battery terminal **42** can be connected with a second bus bar **46** to the second capacitor terminal **127** of the capacitor bank **120**. A second external device terminal **49** can extend from the second bus bar **46**, to connect the device **100** to an external system at a second point, such as a positive connection to a vehicle's electrical system (see, e.g., FIGS. 2A; 6A-6B; 8-18). External device terminals **48** and **49** can be attached to a portion of the lid **113** of the integrated storage device **100**. External device terminals **48** and **49** can be configured to correspond to the existing dimensions of the terminals of a standard OEM battery. It will be understood that the external device terminals described herein can extend from the lid **113**, sidewalls **111A-D**, base **115**, or other portions of energy storage device **100**.

[0075] Referring to FIG. 3, the three-terminal embodiment of device **200** is similar to the two-terminal embodiment of device **100** shown in FIG. 2A, but with an additional external terminal **50** extending through the lid **113** from the second bus bar **46**. Additional electronic components can be connected to one or more of the device terminals **48**, **49** and **50**, battery terminals **41** and **42**, bus bars **44** and **46**, capacitor terminals **45** and **47**, or elsewhere within device **200**, for additional functionality. For example, FIG. 3 shows electronic components **54** that can be positioned between portions **46A** and **46B** of bus bar **46**. Embodiments of hybrid battery/capacitor energy storage devices with additional electronic components and functionality are described below with reference to FIGS. 8-18.

Connection Between the Terminal Bus Bars and the External Device Terminals

[0076] FIGS. 6A and 6B show an embodiment of device **100** with details of the connection between external device terminal **48**, battery lid **133**, device lid **113**, bus bar **44**, and battery terminal **41**. Similar methods can be employed to connect the other external device terminals, bus bars, battery terminals, and capacitor terminals to the battery and device lids described herein, such as the others described with references to devices **100** and **200**. As shown, the external terminal **48** can extend through the device housing lid **113**, through the terminal bus bar **44**, and to the external battery terminal **41**.

[0077] Referring to FIG. 6B, in some embodiments, a protruding stud **48A** of terminal **48** can be extended through an opening **13A** in device lid **113**. In some embodiments, the same portion of the terminal stud **48A** can be further extended into an opening **144** in the terminal bus bar **44**. In some embodiments, the same portion of the terminal stud **48A** can be further extended through the opening **144** in the terminal bus bar **44**, and into a mating portion **43** on the battery terminal. The portion of the terminal stud **48A** can engage with one or more of the aforementioned openings, through a bushing or threaded connection. In some embodiments, the stud can engage with a corresponding portion on the capacitor terminal. Such embodiments can allow one or more external ter-

minals of a combined battery/capacitor energy storage device to function as a consolidated electrical and mechanical junction between the external terminal, bus bar and internal battery terminal, thereby reducing complexity of the energy storage device.

[0078] Thus, some embodiments can allow the battery terminals **41**, **42** of energy storage device **10** to be aligned with the external device terminals **48**, **49** or **50**, and the external device terminals **48**, **49**, or **50** can be installed from outside the energy storage device lid **113**, while also connecting to the bus bars **44**, **46** and the internal battery or internal capacitor terminals.

[0079] In embodiments where such alignment between the battery terminals **41**, **42** and/or capacitor terminals **45**, **47** and the external device terminals **48**, **49** or **50** is not desirable, the external device terminals **48**, **49** or **50** can be installed through the device lid **113**, and connected to one of the bus bars **44**, **46**, without connecting directly to the capacitor battery terminals **41**, **42** or capacitor terminals **45**, **47**.

[0080] The terminal bus bars **44** and **46** can be routed in a number of different ways. In both the embodiments shown in FIGS. 2A and 3, the terminal bus bars are routed in the space between the battery lid **133** and the device lid **113** (see also FIGS. 2A-2B).

[0081] Referring again to FIGS. 6A and 6B, in some embodiments, the external device terminals **48**, **49** or **50** can include a seal **51** configured to provide a seal against the housing lid. Additionally, to prevent galvanic corrosion at the joints between lead battery terminal or lead device external terminal and aluminum EDLC bus bars, a tin plating can be used on the aluminum bus bar, or grease that has been made for electrical joint application can be used. The aforementioned structure and methods can provide for efficient assembly of the terminals and bus bars of embodiments of the combined battery/capacitor device described herein, with reduced number of linkages and parts.

[0082] FIG. 7 is a side view of an embodiment of combined battery/capacitor device **100** with a flexible bus bar **52** connected between battery terminal **41** and a capacitor terminal bus bar **144**. The flexible bus bar **52** can provide sufficient flexibility to compensate for some relative movement between capacitor **20** and battery **30**. Such relative movement may be more prevalent when battery **30** and capacitor **20** are packaged together in a combined battery/capacitor device **10**. The flexibility of flexible bus bar **52** can prevent wear and premature failure on bus bar **52**, thus increasing the reliability and life of energy storage device **10**. The flexibility can be provided to bus bar **52** through its structural attributes and/or material. For example, the flexible bus bar **52** can comprise a material, such as copper bead, stranded wire, or braided wire, that is suitably flexible under a range of reasonable dimensions and environmental conditions for a bus bar as would be understood by a person having ordinary skill in the art. In some embodiments, a flat, braided electrical cable can be used. The ends of the electrical cable can be tinned and hole-punched to form an integrated lug. In some embodiments, bus bar **52** can include one or more curvilinear portions **53** that allow flexion of bus bar **52**, and relative movement between battery **30** and capacitor **20**.

[0083] FIGS. 8-18 are schematic diagrams showing various embodiments of electrical features that can be implemented within a capacitor/battery combination energy storage device, such as one or more of the devices **10**, **100**, **100A**, **100B** and **200**, described above with reference to FIGS. 1-7.

For example, the electrical features may comprise control or regulation circuitry disposed in the enclosure and coupled to the battery and ultracapacitor.

General Two-Terminal Devices

[0084] FIG. 8 is a schematic diagram illustrating an embodiment of a capacitor/battery combination device 300 with two external terminals 48 and 49. The electronics schematically shown for the capacitor/battery combination device 300 can be implemented within the other two-terminal capacitor/battery combination devices described herein. Terminal 48 can be a positive terminal and terminal 49 can be a negative or ground terminal. One or more devices can be connected in parallel between terminals 48 and 49. For example, in the illustrated embodiment, capacitor 30 and battery 20 can be connected in parallel between terminals 48 and 49. When placed within a vehicle, the combined energy storage device 300 can be electrically connected to one or more vehicle loads. For example, the combined device 300 can be connected to a starter 60 or other vehicle loads (illustrated as car load 62). The combined device 300 can also be connected to a power supply, such as an alternator 61, in order to charge the combined device 300 as the vehicle is being driven. Other power supplies can be implemented instead of or in addition to alternator 61, for any of the embodiments described herein and shown in the figures, unless otherwise specified. For example, another external power supply may be connected to device 300 to charge battery 20, such as a charging station for an electric or hybrid vehicle. The order and positioning of the car load 62, alternator 61, and starter 60 can be varied, and is provided in the order shown in FIG. 8 relative to the combined energy storage device 300 for illustrative purposes only.

[0085] Embodiments of the device 300 in FIG. 8 can allow both the capacitor 30 and the battery 20 to be charged from a power supply, such as the alternator 61, and also supply power to a vehicle system, such as the starter 60 or other car loads 62. In a typical vehicle application, both the battery 20 and the capacitor 30 are charged from the alternator 61 with a charge voltage ranging from approximately 12-16V, with a typical average charge voltage being about 14.4V. Prior to being disconnected from the alternator 61, the battery generally maintains a reasonably high state of charge.

[0086] However, after the alternator 61 is shut off or removed as a charging source, the state of charge of the battery 30 may drop at the point the alternator 61 is turned off. For example, if the battery 30 is older, in a colder climate, or has been significantly discharged (such as in a start/stop application) without fully recharging prior to the alternator 61 being shut off, it is not uncommon for the capacity of battery 30 to drop to a point ranging from 65-85% of its rated capacity. As is known, a battery capacity is measured in amp hours with a typical battery having a capacity of 60 amp-hours, although many batteries have more or less capacity depending on their cost and application. It is also not uncommon for the voltage of a battery to drop to approximately 12.4V when the alternator 61 is shut off. When a battery is nearing its end of life cycle, the charge may even decrease to 11.5V or less. In some cases, a battery voltage may drop to as low as 7V after the alternator 61 is shut off. These large voltage drops in the battery 30 can reduce the battery's life, prevent or reduce the likelihood of a reliable starter crank, or cause other problems described herein with respect to a low battery voltage.

[0087] Providing the capacitor 20 in parallel with the battery 30, as shown in FIG. 8, has been found to buffer these and one or more other aforementioned limitations of a battery-only system. For example, one embodiment of the invention is a combined battery/capacitor system that allows a bi-directional flow between the capacitor 20 and battery 30. This provides a system wherein the capacitor 20 is configured to recharge the battery 30 when the state of charge and voltage in the capacitor 20 is higher than the battery 30. The increased cycle efficiency of the capacitor 20 can also allow the capacitor 20 to provide such function while increasing the life of the battery 30, and thus the overall lifecycle of the device 10. In effect, the capacitor 20 can absorb the "work" or power requirements that would otherwise be performed by the battery 30. In addition, the efficient charge acceptance and discharge rate of the capacitor 20, and its cycle efficiency, can allow it to mitigate some of the spikes and drops in power typical during operation of the device, such as in a start/stop application. The two-terminal combined energy storage device 300 in FIG. 8 can also be more easily configured to replace a standard two-terminal OEM battery, for example, as a drop-in replacement.

[0088] The power management characteristics of embodiments of the two-terminal combined battery/capacitor energy storage device 300 can be affected when the battery 30 and capacitor 20 are configured in parallel, and when free-flow of current is allowed between the battery 30, capacitor 20, and starter 60. For example, any current supplied to the vehicle starter 60 from the combined storage device 300 during a vehicle start event will be generated proportionally from both the battery 30 and the capacitor 20, and will be affected by the resistance of the battery 30, the ESR of the capacitor 20, and the capacitance of the capacitor 20. For example, in a test of such a configuration, during a typical vehicle starting event, the battery 30 supplied approximately 200 A of current and the ultracapacitor contributed approximately 600 A of current.

[0089] Additionally, because current can free flow between the capacitor 20 and the battery 30, the available charge and voltage of the capacitor 20 will also generally move towards a charge and voltage equilibrium relative to that of the battery 30 when the alternator 61 or other power source is in an off state. Such voltage equilibrium may generally be less than the state of charge and voltage of the capacitor 20 if it were to be electrically isolated from the battery 30. For example, as described above, when the combined device is at rest for a period of time, or when the battery 30 is not fully recharged, the battery voltage and state of charge may drop. Thus, there may be advantages to embodiments of a combined battery/capacitor storage device that at least partially electrically isolates the battery and capacitor, to reduce or prevent the capacitor from losing charge to the battery when the alternator is off.

Three-Terminal Current Controlling Devices

[0090] FIG. 9 shows an embodiment of a combined battery/capacitor energy storage device 400, with many similar components as FIG. 8. A difference is that the embodiment of energy storage device 400 in FIG. 9 can include a third terminal 50, such as that shown in FIG. 3. The electronics schematically shown for the capacitor/battery combination device 400 can be implemented within the other three-terminal capacitor/battery combination devices described herein. Terminal 48 can comprise a first positive terminal configured

to connect with the alternator 61. Terminal 50 can comprise a second positive terminal that is configured to connect with starter 60. Such an embodiment can allow the starter 60 to be electrically configured on the same terminal of the device 300 as, for example, the capacitor 20, and the alternator 61 to be electrically configured on the same terminal as the battery 30. Of course, embodiments are not limited to only connecting a starter 60 to the first positive terminal. Terminals 48 and/or 50 can be configured to connect with other car loads 62 that would benefit from being directly connected to a capacitor or a battery.

[0091] A rectifier 63 can be positioned between the alternator terminal 48 and the starter terminal 50. The rectifier 63 can be configured to allow current flow from the alternator 61 to the capacitor 20, allowing the capacitor 20 to be charged, while preventing or reducing current flow from the capacitor 20 to terminal 48 and battery 30. Such an embodiment can at least partially electrically isolate the capacitor 20 from the battery 30. Thus, some such embodiments also isolate the starter 60 from the battery 30. Rectifier 63, or any other rectifiers described herein, can comprise a diode, a synchronous rectifier, a transistor, such as a controllable FET, or other suitable device to provide such function.

[0092] Embodiments that position the starter 60 on the same terminal as the capacitor 20, and isolate the capacitor from the battery 30 (by allowing only unidirectional current flow therebetween), can provide several benefits. For example, such embodiments can allow substantially only the power and current stored in the capacitor 20 to be provided to the starter 60 during a start event, reducing or eliminating the aforementioned affects of the battery resistance that may occur. Such isolation of functionality between the capacitor 20 and battery 30 can allow the capacitor 20 to supply power to quick or high power pulse devices, such as the starter 60, and allow the battery 30 to contribute power to devices with medium or longer period demands. Such embodiments can also prevent the state of charge and voltage of capacitor 20 from being reduced by the aforementioned lower voltage of the battery 30, or from reaching a combined battery/capacitor equilibrium state of voltage. As described above, the battery 30 may have an undesired, lower voltage because the battery has been accidentally discharged, insufficiently recharged (for example, in a start/stop application), or is operating in a cold environment. The battery may have otherwise reached a lower state of charge due to lower charge acceptance. By at least partially isolating the battery 30 and capacitor 20 with the rectifier 63 in a three-terminal system, the capacitor 20 can remain at a higher voltage and state of charge when the alternator 61 or another power supply is turned off, separate from the state of charge, voltage and capacity of the battery 30. Such isolation thus can also provide an overall higher energy to the starter 60 from the capacitor 20, without the limiting effects of the battery 30.

[0093] The aforementioned isolation of the battery 30 from the capacitor 20 and starter 60 can also reduce the load on the battery 30 during engine crank, thus improving the life of the battery 30, for example, during start/stop applications. Thus, these embodiments can improve vehicle start efficiency, and reduce the likelihood of the situation where the system can't provide sufficient power to the starter 60 to start the vehicle. For example, in average conditions, the available discharge voltage at the starter terminal 50, and thus of the capacitor 20, after the alternator 61 was turned off was approximately 13.5V (the alternator voltage minus the voltage drop over the

rectifier, or $\sim 14.2 - 0.7 = 13.5V$). In similar conditions, the discharge voltage at the alternator terminal 48, and thus, of the battery 30, dropped to approximately 12.6V after the alternator 61 was turned off.

[0094] The increase in voltage and state of charge provided by using the isolated capacitor 20 and starter 60 may further enhance vehicle startup at low temperatures. For example, a battery's voltage may drop significantly more at a low temperature under load than that of a capacitor, resulting in low cranking power and efficiency. For example, a battery charged at approximately 15.0 volts (at approximately -10 degrees F.) and discharged at approximately 500 amps results in a 2 second discharge voltage of approximately 9.5V. In comparison, a capacitor charged at approximately 15.0 volts (at approximately -10 degrees F.) and discharged at approximately 500 amps, results in a discharge voltage of approximately 13.5V. Thus, under these example conditions, a capacitor provides approximately 4 additional volts to a starter. Such higher capacitor voltage in turn results in higher starter cranking power and motor velocity on the next engine crank and faster starting; thus the above example of 4 volts additional cranking power can provide approximately 40% faster crank speed.

[0095] At lower temperatures, a capacitor can store additional energy, even with respect to another capacitor, further enhancing the benefits of isolating the capacitor during vehicle startup. For example, the stored energy of a capacitor is defined by the equation $E = \frac{1}{2} C V^2$, where C is the capacitance and V is the voltage. Thus, for example, a 400 farad capacitor at -10° F. receiving a typical vehicle alternator 61 voltage supply of 15 volts (at that temperature) can store 45 kJoules of energy. This is significantly more energy than a similar 400 farad capacitor at 160° F. receiving a typical vehicle alternator 61 voltage supply of 13.4 volts (at that temperature), which can only store 36 kJoules of energy. Such increased energy corresponds to increased cranking power, and increased start reliability at cold temperatures.

[0096] Rectifier 63 can be any of a variety of sizes, depending on the application. In an example using a standard vehicle battery (approximately 12V), a 400 amp diode was employed. However, it is anticipated that diodes rated in a range from approximately 300 to 1000 amps may provide similar results.

[0097] FIG. 10 shows another embodiment of a three-terminal combined battery/capacitor energy storage device 500, with many similar components as FIG. 9. The electronics schematically shown for the capacitor/battery combination device 500 can be implemented within the other three-terminal capacitor/battery combination devices described herein. In the illustrated embodiment, a current limiter 65 can be employed between the rectifier 63 and the starter terminal 50. Any suitable current-limiting devices can be employed, such as a positive-temperature coefficient (PTC) thermistor, a self-resetting circuit breaker, an in-rush limiting resistor with a bypass switch, and the like. The current limiter 65 can be employed to reduce the size of the rectifier 63, or for other reasons.

[0098] The current limiter 65 can be configured to open (and thus increase its resistance) when the current to which it is exposed is high. For example, such a high current situation may be typical of an engine start event, when the capacitor 20 is being used to crank the starter 60, as described above. When an increased current is drawn from the battery 30, the battery's operational life can be reduced. The current limiter

65 prevents or reduces current draw from the battery **30** to the starter **60** during the starter **60** crank, increasing the life of battery **30**. Additionally, by preventing or reducing the current draw from the alternator terminal **48** to the starter **60** through the rectifier **63**, the current limiter **65** can also protect the rectifier **63** from increased current levels. Such current protection to the rectifier **63** can allow it to be sized smaller. For example, a system that employs a current limiter **65** may reduce the size of the rectifier **63** to those rated between approximately 25 to 400 amps. A smaller diode can allow the space envelope of device **10** to be smaller, or to be the same size, but with increased capacity of the battery and/or capacitor. A current limiter **65** can be implemented in series with the other rectifiers described in other embodiments herein, to provide similar functionality.

[0099] FIG. **11** shows another embodiment of a three-terminal combined battery/capacitor energy storage device **600**, with many similar components as FIGS. **9-10**. The electronics schematically shown for the capacitor/battery combination device **600** can be implemented within the other three-terminal capacitor/battery combination devices described herein. In this embodiment, a DC/DC converter **66** can be positioned between the alternator terminal **48** and the starter terminal **50**. The DC/DC converter **66** can provide similar current management function as the aforementioned rectifier **63**, FET **64**, or rectifier **63** used in combination with a current limiter **65**. The DC/DC converter **66** may also block the battery **30** from providing the entirety of the cranking current, and allow the capacitor **20** to be charged to a voltage greater than that of the battery **30**. The DC/DC converter **66** may also charge the capacitor to different voltages depending on different environmental conditions; the capacitor may be charged to a higher voltage at lower temperatures, or lower voltage at higher temperatures. A DC/DC converter can control in-rush current to the battery, to reduce battery temperature increases. A DC/DC converter can also regulate the voltage of the capacitor to prevent an over-voltage condition.

[0100] FIG. **12** shows another embodiment of a three-terminal combined battery/capacitor energy storage device **700**, with an embodiment of the DC/DC converter **64** shown in FIG. **11**. The electronics schematically shown for the capacitor/battery combination device **700** can be implemented within the other three-terminal capacitor/battery combination devices described herein. In this embodiment, the DC/DC converter **64** includes a boost controller **70** configured to control an FET **64** positioned between the ground terminal **49** and the rectifier **63**. It will be understood that other types of switching devices or transistors than FET **64** can be implemented. The FET **64** and boost controller **70** can provide charge to the capacitor **20** through the rectifier **63**, to allow capacitor **20** to be charged to a voltage greater than battery **30**, while isolating battery **30** from current during starter crank.

[0101] An inductor **71** can be positioned between the alternator terminal **48** and the rectifier **63**, in parallel with the boost controller **70** and the FET **64**. The inductor **71** can comprise a wire or bus bar with a saturable core surrounding it. Thus, inductor **71** can comprise a saturable inductor. The inductor **71** and the rectifier **63** can passively charge capacitor **20** to a voltage greater than battery **30**, while isolating battery **30** from current during starter crank. For example, when the voltage of capacitor **20** is lower than battery **30** (e.g., after a start event), the capacitor **20** can be charged passively through inductor **71** and rectifier **63** up to the battery voltage. After an initial charge through inductor **71** and **63**, the boost controller

70 can activate FET **64**, allowing the capacitor **20** to actively charge, to a voltage greater than battery **30**. By including both the passive and active charging, a smaller and less expensive controller **70** and FET **64** can be implemented, and the charge time to the capacitor **20** is reduced. Thus, the boost controller circuit shown in FIG. **12** can provide similar function as other DC/DC converters, but at lower complexity and cost.

[0102] FIG. **13** shows another embodiment of a three-terminal combined battery/capacitor energy storage device **800**, with many similar components as FIG. **12**. The electronics schematically shown for the capacitor/battery combination device **800** can be implemented within the other three-terminal capacitor/battery combination devices described herein. In this embodiment, a second rectifier **73** can be positioned between the alternator terminal **48** and the starter terminal **50**, in parallel with the inductor **71A** and rectifier **63**. In some embodiments, inductor **71A** is not saturable. The boost charger circuit shown in FIG. **13** can provide similar function as the circuit shown in FIG. **12**. In this embodiment, the rectifier **73** can charge the capacitor to a voltage approximately equal to that of the battery. The boost charger can be turned on and raise the capacitor voltage to a set value above the battery voltage. The boost charger can include an inductor **71A** (which is typically smaller than the inductor **71** of FIG. **12**), the rectifier **63** (which is typically smaller than rectifier **73**), FET **64** and boost controller **70**. The boost charger can be of any suitable topology or implementation.

Two-Terminal Devices—Switching

[0103] FIG. **14A** shows another embodiment of a two-terminal combined battery/capacitor energy storage device **900**, with many similar components as FIGS. **9-13**. The electronics schematically shown for the capacitor/battery combination device **900** can be implemented within the other two-terminal capacitor/battery combination devices described herein. In this embodiment, a first electronic switch **75** can be positioned to allow the capacitor **20** to be electrically connected to, and disconnected from, terminal **48**, or its associated terminal bus. A second electronic switch **77** can be configured to allow the battery **30** to be electrically connected to and disconnected from terminal **48**, or its associated terminal bus. The device **900** can include a rectifier **63**. The rectifier **63** can be configured in parallel with switch **75** to allow the capacitor **20** to be charged while switch **75** is open, while preventing current flow in the opposite direction. For example, capacitor **20** can be passively charged through rectifier **63** from alternator **61**, regardless of the positioning of switches **75** and **77**. In some embodiments, a current limiter, such as a thermistor, may be included in series with the rectifier **63** to reduce the current load experienced by the rectifier **63** and the battery **30**, as shown in FIG. **10**.

[0104] The switches **75**, **77** can be any of a number of suitable configurations, such as a semiconductor switch or a mechanical contactor. Suitable semiconductor switches include, for example, a various types of FETs or IGBTs. The switches **75**, **77** can be configured to be operated manually or automatically. Of course, it should be realized that some embodiments may have combinations wherein the rectifier **63**, or one or more of the electronic switches **75**, **77** are not used. In some embodiments, an optional DC/DC converter, such as those shown in FIGS. **11-13**, can be positioned between terminal **48** and capacitor **20**.

[0105] Switches **75** and/or **77** can be electronically controlled with a charge controller **74**. Any of a number of con-

trollers described herein can be used to control switches **75** and/or **77**; for example, the charge controller **74** can be a micro controller. Alternatively, the electronic switches **75** and/or **77** can be controlled by discrete logic. The charge controller **74** can be provided with one or more of the following inputs: voltage sense from the capacitor (I_{ve}), voltage sense from the battery (I_{vb}), and/or current sense (I_b) from the battery output. Other inputs, such as temperature sensors, may also be implemented to provide additional functionality. These inputs can be provided using any of a variety of sensors or other devices suitable of sensing an environmental condition and providing an input to the charge controller **74**. The charge controller **74** can provide one or more of the following outputs: output to control switch **75** (O_a) and/or output to control switch **77** (O_b). It will be understood that one or more of the aforementioned switching, sensing, and controlling functionality can be provided through one or more separate or integrally formed components. For example, a voltage sensor and switch may be combined in a single unit, and/or the switch and microcontroller can be a suitable relay that switches directly in response to an input signal, for example, without complex electronics.

[0106] FIG. 14B shows another embodiment of a two-terminal combined battery/capacitor energy storage device **1000**, with many similar components as FIGS. 9-14A. The electronics schematically shown for the capacitor/battery combination device **500** can be implemented within the other two-terminal capacitor/battery combination devices described herein. The embodiment shown in FIG. 14B is similar to that in FIG. 14A, but with different positioning of the rectifier **63** relative to switches **75** and **77**. In FIG. 14B, the rectifier **63** is connected to battery **30**, without intervening switch **77**. Thus, device **1000** in FIG. 14B can provide a path to the capacitor **20** from the battery **30**, to passively charge the capacitor **20** through the rectifier **63** from battery **30**, regardless of the open or closed status of switches **75** and **77**. As shown in FIG. 14B, device **10** can include the current limiter **65** as shown. The functionality of the switches **75** and **77** in FIG. 14B can otherwise be similar to that described herein with reference to FIG. 14A or 15.

Three-Terminal Devices—Switching

[0107] FIG. 15 illustrates a substantially similar embodiment as FIG. 14A, but in a three-terminal combined battery/capacitor energy storage device **1110**. The electronics schematically shown for the capacitor/battery combination device **1100** can be implemented within the other three-terminal capacitor/battery combination devices described herein. FIG. 15 does not include some of the components shown in FIG. 14A, such as all the inputs, outputs, and switch **77**, but can be configured with these components, to provide similar functionality as the embodiments described herein with reference to FIG. 14A.

[0108] The switched configuration of the embodiments of the combined battery/capacitor energy storage devices shown and described with reference to FIGS. 14A-14B and 15 can be controlled in a number of different ways, to provide a number of different functions, examples of which follow:

Improved Start Function

[0109] The embodiments in this section can improve vehicle start efficiency, and reduce the likelihood of the situation where the battery **30** can't provide sufficient power to

the starter **60** to start the vehicle. For example, the battery **30** may have an undesired, lower voltage because the battery **30** has been accidentally discharged, insufficiently recharged, is operating in a cold environment, or the battery **30** has otherwise reached a lower state of charge due to lower charge acceptance or lower capacity. For example, in a start/stop application, a battery may be discharged without sufficient periods of charging to fully recharge.

[0110] Referring to FIG. 14A, when the vehicle engine is ON, switches **75** and **77** can be in a closed position. In this mode of operation, both the battery **30** and the capacitor **20** can be charged from the alternator **61** to a voltage, ranging for example, in a vehicle application, from between approximately 12 and 16 V, or an average of about 14.4V. A vehicle OFF state can be detected, for example, when the alternator **61** or other power source otherwise stops delivering sufficient charging voltage. In some embodiments, the vehicle OFF state can be detected through inputs I_b , I_{vb} , and/or other input (s) to the charge controller **74**. Once the alternator **61** stops delivering charging voltage to the battery **30**, the voltage of the battery **30** may drop under load to a reduced output voltage, depending on its state of charge at the point the alternator **61** stops. To prevent the capacitor **20** from being discharged to this open circuit voltage of the battery **30**, switch **75** can be opened, for example, through output signal O_a from the charge controller **74**, to isolate the capacitor **20** from the battery **30** and terminal **48**. In some embodiments, switch **75** can remain open during the entire time the vehicle is turned OFF. However, it will be understood that some embodiments can allow switch **75** to close for a period of time when the vehicle is OFF, and still provide the improved starting function described herein.

[0111] The charge controller **74** can be configured to detect an event, for example, of the starter **60** cranking, by monitoring I_b , the current out of the energy storage device **900**, the rate of change of the current output (dI/dt) and/or the change in voltage of the battery **20** (dV/dt), or a combination thereof. When the event is detected, switch **75** can be closed such that the capacitor **20** can supply power to the starter **60**. Because the capacitor **20** was previously at least partially isolated from the battery open circuit voltage during periods when switch **75** was open, once switch **75** is closed during startup, the capacitor **20** can provide voltage to the starter **60** at a higher voltage than the battery open circuit voltage. Such higher voltage provided by the capacitor **20** can increase crank speed of the starter **60**, and improve the reliability with which the starter **60** will start a vehicle.

[0112] For example, as described above, in a vehicle application, the charge voltage of the battery **30** and capacitor **20** while the alternator **61** is running may range between approximately 12 and 16V, with an average of approximately 14.4V. After a stop condition of the alternator **61**, the battery open circuit voltage may drop to a point between approximately 12 and 13V. Through the aforementioned control of switch **75**, and the capacitor's tendency to retain its state of charge, the drop in the open circuit voltage of the capacitor **20** may be less than that of the battery **30**. Thus, the capacitor **20** may remain at an increased open circuit voltage during the stop condition of the alternator **61** relative to that of the battery **30**, and can provide increased voltage and starting power during vehicle startup. It is noted that in embodiments where optional switch **77** is not present, the battery **30** will contribute to a reduced portion of the starting current in

parallel with the capacitor 20, upon the closing of switch 75 and the use of the capacitor 20 during the starter 60 crank.

[0113] In some embodiments, the voltage of the capacitor 20 when the alternator 61 is OFF may be reduced from that when the alternator 61 is running, based upon a voltage drop over the rectifier 63. However, in some embodiments an “ideal diode” circuit can be implemented. Such a circuit can monitor the voltage on both sides of switch 75 when the alternator 61 is on. The circuit can close switch 75 when the voltage on the alternator 61 side of switch 75 reaches a monitored level. Closing switch 75 can bypass the rectifier 63 and allow the voltage of the capacitor 20 to increase and approach that of the alternator 61. In such an embodiment, when the alternator 61 is OFF, and switch 75 is opened, the capacitor 20 can remain at an open circuit voltage approximately the same as the voltage of the alternator 61.

[0114] In embodiments including optional switch 77, switch 77 can be opened, for example, by the charge controller 74, to disconnect current being supplied from the battery 30, and thus isolate the capacitor 20 and battery 30. For example, switch 77 can be open during periods that switch 75 has been closed to isolate the capacitor 30 from the battery 20, and allow only the increased capacitor voltage (and power) to crank the starter 60 during the aforementioned vehicle start. It may also be desired to supply power from the capacitor to one or more other vehicle loads, such as emergency lighting. Switch 77 can be closed again, for example, when the capacitor voltage is approximately equal to the battery voltage or when the end of a cranking event has been detected. The aforementioned isolation can reduce the load on the battery during engine crank, thus improving the life of the battery 30, for example, during start/stop applications, and reducing cycling down effects. Such isolation can also provide an overall higher energy to the starter 60 from the capacitor 20, with the battery 30 at least partially isolated from the starting current.

Recuperate Braking Energy

[0115] Some embodiments can provide additional functionality in a hybrid vehicle, a vehicle with an internal combustion engine, or other vehicles equipped with a starter 60. For example, some vehicles may include a starter 60 generator, with the ability to generate, and thus recuperate or regenerate, energy when the vehicle is braking. However, many battery chemistries have a lower charge acceptance than a capacitor or ultracapacitor, and thus batteries may have lower efficiency than a capacitor in receiving and storing such regenerated braking energy. The following embodiments can allow some or substantially all of the regenerated braking energy to be directed to the capacitor instead of the battery, to improve the efficiency in the regenerated braking and mitigate the limitations in charge acceptance that a battery may impart to the energy storage device.

[0116] When the vehicle engine is ON, switches 75 and 77 can be configured in a closed position. During this mode of operation, both the battery 30 and the capacitor 20 can be charged by the alternator 61 to a voltage, ranging from 12-16V, or typically a 14.4V average in a typical vehicular application, as described above. The charge controller 74 can detect that a regenerative braking event is initiated by detecting a significant increase in voltage relative to that provided by the alternator 61. For example, in the aforementioned typical vehicular application, the average voltage during a regenerative braking event may increase to a range between

approximately 14.4V and 18V. However, it will be understood that voltage during a regenerative braking event may increase up to any point within the voltage limitations in which the regenerative braking system is employed. When the charge controller 74 detects that a regenerative braking event is taking place, switch 77 can be opened to direct the regenerative braking energy only to the capacitor 20. Such capacitor isolation can allow the energy captured in the capacitor to be stored and then used in the next cranking event (for example, for a vehicle with start/stop functionality), to provide power to other auxiliary loads in the vehicle (such as lighting, air conditioning, cabin heating and the like), or to recharge the battery 30 by closing switch 75. In some embodiments, when the capacitor voltage is detected to be at a point indicating that the capacitor 20 has reached a full state of charge, switch 75 can be opened again and switch 77 can be closed, isolating the capacitor 20 from the system, and redirecting the regenerative braking energy to the battery 30. In some embodiments, both switch 75 and switch 77 can be closed in a regenerative braking event, to allow the regenerative braking energy to be directed to both the capacitor 20 and battery 30. In such an embodiment, the regenerative braking energy and current may be split between the capacitor and battery.

Trickle Charging in the Battery from the Capacitor to Reduce Cycle-Down Effect

[0117] In some embodiments, when the vehicle engine is ON, switches 75 and 77 are in a closed position. In this mode of operation, both the battery 30 and the capacitor 20 can be charged from the alternator 61 with a charge voltage ranging from 12-16V, or a typical average charge voltage of 14.4V. In some embodiments, the charge controller 74 can detect that the vehicle is turned OFF when the alternator 61 is no longer delivering sufficient charging voltage. At this point, switch 75 can open to reduce the likelihood or prevent the capacitor 20 from discharging to the battery 30 and the other loads connected to the battery 30 (or terminal 48). Prior to being shut off from the charging voltage supply from the alternator 61, the battery 30 generally maintains a reasonably high state of charge.

[0118] However, after the alternator 61 is shut off or removed as a charging source, the state of charge of the battery 30 may drop at the point the alternator 61 is turned off. For example, if the battery 30 is older, in a colder climate, or has been significantly discharged (such as in a start/stop application) without fully recharging prior to the alternator 61 being shut off, it is not uncommon for the battery's capacity to drop to a point ranging from 65-85% of its rated capacity. As is known, a battery capacity is measured in amp hours with a typical battery having a capacity of 60 amp-hours, although many batteries have more or less capacity depending on their cost and application. It is also not uncommon for the voltage of a battery to drop to approximately 12.4V when the alternator 61 is shut off. When a battery is nearing its end of life cycle, the charge may even decrease to 11.5V or less. In some cases, a battery voltage may drop to as low as 7V after the alternator 61 is shut off. These large voltage drops in the battery can reduce the battery's life or may be a sign that the battery is already at the end of its life cycle. Such scenarios can prevent or reduce the likelihood of a reliable starter 60 crank, or cause other problems described herein with respect to a low battery voltage.

[0119] Some embodiments can help compensate for the aforementioned problems with battery state of charge, capac-

ity and voltage that can occur after the battery 30 loses its supply of power from the alternator 61. For example, switches 75 and 77 can be closed, allowing the capacitor 20 to supply energy to the battery 30, and thus restoring all or a portion of the previously-lowered state of charge or open circuit voltage of the battery 30. Such a “trickle charge” event of the capacitor 20 to the battery 30 can occur at various times after shutting down the alternator 61. However, it may be beneficial to close switch 75 and trickle charge the battery 30 within a relatively short time period (less than ten seconds) after the alternator 61 is shutoff, so as to maintain the voltage of the battery 30 closer to or approximately at its charging voltage, and reduce the likelihood of the voltage of the battery 30 from dropping significantly. Such an embodiment will reduce the amount of work required by the battery 30, and thus reduce wear on the battery 30, increase the battery’s life, and improve the overall efficiency of the vehicle in which the combination capacitor/battery device 900 is employed. These embodiments can also have a positive effect on the charge acceptance of the battery 30 when resumed in operation. In sum, the work required from the voltage cycling is transferred to the capacitor, which is designed for such cycling, instead of the battery 30. When the battery 30 is trickle charged by the capacitor 20 in a start/stop application, such as a hybrid vehicle, the vehicle’s fuel efficiency can be improved, due to the improved efficiencies of the battery 30.

[0120] The length of time in which switch 75 is closed (to trickle charge the battery 30 with the capacitor 20) may vary, but generally ranges from approximately one hour to approximately four hours. The trickle charge can be applied continuously, but can also be applied intermittently. For example, a trickle charge may be applied with a pulse-width-modulated (PWM) control, which may get rid of surface ion layers within the battery plates, allowing the battery to charge more quickly. A trickle charge may also be applied to the battery a single time while a vehicle is at rest, or several times over a given time period.

[0121] In a test using a trickle charge of a battery with an ultracapacitor, a group 31 AGM Pb battery was “cycled down” to 12.45 OCV, and was allowed to stand for two months. At this point, the battery’s charge acceptance was measured at 6 amps at 14.4V at 45 degrees F. For five consecutive days, the battery received 4 approximately evenly spaced charges from an ultracapacitor that was initially charged to 14.4V. The new OCV of the battery after receiving such trickle charges from the capacitor was measured at 12.64V. When the battery was discharged back to 12.45V, the measured charge acceptance of the battery was 28 amps. This test demonstrates the benefit in charge acceptance to a cycled down battery in response to a trickle charge. The related efficiencies that such benefits of the trickle charge described herein may reduce the amount of work required by a battery in a typical start/stop application of a hybrid vehicle by 200-250 amp hours over a year of normal use.

[0122] The amount of voltage in the capacitor 20 and battery 30 can be monitored during the trickle charge, to prevent the trickle charge from dropping the capacitor 20 and battery 30 voltage from dropping to a point below which the starter 60 cannot start (about 12V). If the voltage reaches such a low voltage point during a trickle charge, the charge controller 74 can re-open switch 75, and retain enough voltage in the capacitor 20 to start the starter 60.

[0123] One or more of the aforementioned functions with respect to the system in FIG. 14A can be provided in the other

two-terminal, two switch embodiment of FIG. 14B, or the three-terminal configuration shown in FIG. 15 with only switch 75 and the rectifier 63. An advantage of the embodiments shown in FIGS. 14A and 14B is that they are two-terminal designs, and may more easily replace existing two-terminal OEM batteries. However, the three-terminal embodiment can provide some similar functionality, in a simpler application, for example, without switch 77. Such embodiments can separate the current flow from the capacitor 20 from that of the battery 30, and allow the starter 60 to receive a higher voltage from only the capacitor 20 (when switch 75 is open). Such embodiments can provide similar benefit as the embodiments shown in FIG. 14A and described herein in the section entitled “Improved Start Function.” Additionally, switch 75 can be moved to an open position, to direct energy from regenerative braking to the capacitor 20 only, or switch 75 can be moved to the closed position, to direct energy from the regenerative braking to both the capacitor 20 and the battery 30, to provide similar benefit as the embodiments shown in FIG. 14 and described herein in the section entitled “Recuperate braking energy.” Additionally, switch 75 can be moved to a closed position, to allow the capacitor 20 to trickle charge the battery, to provide similar benefit as the embodiments shown in FIG. 14A and described herein in the section entitled “Trickle charging the battery from the capacitor to reduce cycle-down effect.”

Resistive Bridge

[0124] FIG. 16 shows another embodiment of a three-terminal combined battery/capacitor energy storage device 1200, with many similar components as FIGS. 9-15. The electronics schematically shown for the capacitor/battery combination device 1200 can be implemented within the other three-terminal capacitor/battery combination devices described herein. In this embodiment, a current limiter 76 can be positioned between starter terminal 50 and alternator terminal 48. In some embodiments, device 1200 can comprise a two-terminal device, similar to those other two-terminal devices described herein. For example, device 1200 can be configured without terminal 48, and with the current limiter positioned between terminal 50 and battery 30, and with the alternator 61 and car load 62 connected to terminal 50. The current limiter 76 can comprise a resistive bridge comprising one or more resistors. The current limiter 76 can comprise one or more positive-temperature-coefficient resistors, a self-resetting circuit breaker, or another suitable current-limiting device. The current limiter 76 can reduce the current draw into the battery 30 during the crank of a starter by capacitor 20, similar to other embodiments of combined energy storage devices described herein, but with less components, lower cost, and increased reliability. The resistance of current limiter 76 can be sized based upon the sizing, load profile, and inherent resistance of the battery 30 and the ESR of the capacitor 20. Generally the current limiter 76 can be sized suitably large enough to provide the aforementioned benefits of reducing the current draw from the battery, without being so large that the recharge rate of the capacitor would be decreased below a useful value. In general, the current limiter should be sized so the system time constant (the resistance times the capacitance) is approximately 10 to 100 times larger than the duration of the peak power demand of the system. In most automotive applications, the peak power demand lasts between approximately 1 and 10 seconds so the current limiter should be sized such that the time constant of device 1200

is between approximately 10 and 1000 seconds. In some embodiments, the time constants for device **1200** can be between approximately 1 and 10,000 seconds. For example, a resistive bridge rated to 2000 W or more can be implemented within a combined battery/capacitor device that includes a battery with an open circuit voltage of 288V, and a capacitor in parallel with approximately 24 F of capacitance. The current limiter **76** can be implemented in addition to one or more of the other embodiments described in FIGS. 9-15.

Rectifier Network

[0125] FIG. 17 shows another embodiment of a two-terminal combined battery/capacitor energy storage device **1300**, with many similar components as FIGS. 9-16. The electronics schematically shown for the capacitor/battery combination device **1300** can be implemented within the other two-terminal capacitor/battery combination devices described herein. In this embodiment, device **1300** includes a network of rectifiers **63**, **73**, and **78** running in a string between two batteries **30A** and **30B** connected in parallel. Batteries **30A** and **30B** can be of approximately the same rated voltage and capacity. The system of rectifiers **63**, **73** and **78**, and batteries **30A** and **30B** can be connected in parallel with capacitor **20**.

[0126] The embodiment of device **1300** shown in FIG. 17 can provide some of the benefits as those combination devices described herein that include a DC/DC converter or switched system, such as those shown in FIGS. 11-15. For example, batteries **30A** and **30B** can work in parallel to power the car load **62** when the capacitor **20** is depleted below a certain level, such as at or below the rated voltage of batteries **30A** and **30B**. During recharge, the capacitor **20** can receive the power first, until the capacitor **20** reaches a certain level, such as twice the rated voltage of batteries **30A** and **30B**. Subsequently, the power can be used to recharge the batteries **30A**, **30B**. The recharge of the batteries **30A**, **30B** is presumably at a lower effective rate, due to the batteries' higher internal resistance. The embodiment of device **1300** in FIG. 17 can be implemented with only solid state components, and thus may be simpler with respect to a device with a DC/DC converter or switched system. Thus, the embodiment of FIG. 17 can be more reliable, and may be provided at a lower cost than some other hybrid battery/capacitor energy storage devices.

Self-Balancing Device

[0127] FIG. 18 shows another embodiment of a two terminal combined battery/capacitor energy storage device **1400**, with many similar components as FIGS. 9-17. The electronics schematically shown for the capacitor/battery combination device **1400** can be implemented within the other two-terminal capacitor/battery combination devices described herein. In this embodiment, capacitor **20** can comprise a capacitor bank with a plurality of capacitors **20A-20F** connected in series, and battery **30** can comprise a battery bank with a plurality of batteries **30A-30F** connected in series. In some embodiments, the number of capacitors and the number of batteries implemented within energy storage device **10** can be the same, to provide better balancing between the batteries and capacitors as described further below. A plurality of interconnects **80A-80E** can extend between the capacitor **20** and battery **30**, wherein each interconnect can include a first end connected between a corresponding adjacent pair of capacitors and a second end connected between a corresponding adjacent pair of batteries. For example, interconnect **80A** can

include a first end **81A** connected at a point between capacitors **20A** and **20B**, and a second end **82A** connected at a point between batteries **30A** and **30B**, and so forth, for the remainder of the interconnects, batteries, and capacitors. Interconnects **80A-80E** can comprise a wire, bus bar or other electrical connection. Interconnects **80A-80E** can comprise a wire, bus bar, or other electrical connection, without other electrical components extending between adjacent capacitors and batteries. In some embodiments, it will be understood that the number of batteries and capacitors shown (six) and the number of interconnects (five) are for illustrative purposes.

[0128] The embodiment of device **1400** shown in FIG. 18 can provide balancing of the voltage of individual capacitors **20A-20F** within capacitor bank **20** relative to each other, and the overall output voltage of capacitor bank **20**. The embodiment also can provide balancing of the voltage of individual batteries **30A-30F** within battery bank **30** relative to each other, and the overall output voltage of battery bank **30**. Such balancing can reduce the differences between the voltages of the individual capacitors and/or batteries. Such balancing can avoid certain capacitors or batteries being charged to a higher or lower voltage than other capacitors or batteries, which can have an impact on the service life of the capacitor **20**, battery **30**, or the hybrid energy storage device **1400**. Such balancing can also prevent complete failure of the overall capacitor bank **20** or battery bank **30** in the event of a failure of one or more individual capacitors **20A-20F** and batteries **30A-30F**. The balancing circuit in FIG. 18 is simpler, less expensive, and more robust than some balancing circuits that provide similar function, but with more complexity, such as switches, controllers, and the like.

Clarifications Regarding Terminology

[0129] Those having skill in the art will further appreciate that the various illustrative logical blocks, modules, circuits, and process steps described in connection with the implementations disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention. One skilled in the art will recognize that a portion, or a part, may comprise something less than, or equal to, a whole.

[0130] The various illustrative logical blocks, modules, and circuits described in connection with the implementations disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors,

one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[0131] The steps of a method or process described in connection with the implementations disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of non-transitory storage medium known in the art. An exemplary computer-readable storage medium is coupled to the processor such the processor can read information from, and write information to, the computer-readable storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal, camera, or other device. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal, camera, or other device.

[0132] Headings are included herein for reference and to aid in locating various sections. These headings are not intended to limit the scope of the concepts described with respect thereto. Such concepts may have applicability throughout the entire specification.

[0133] The system is comprised of various modules as discussed in detail below. As can be appreciated by one of ordinary skill in the art, each of the modules comprises various sub-routines, procedures, definitional statements and macros. Each of the modules are typically separately compiled and linked into a single executable program. Therefore, the following description of each of the modules is used for convenience to describe the functionality of the preferred system. Thus, the processes that are undergone by each of the modules may be arbitrarily redistributed to one of the other modules, combined together in a single module, or made available in, for example, a shareable dynamic link library.

[0134] The invention disclosed herein may be implemented as a method, apparatus or article of manufacture using standard programming or engineering techniques to produce software, firmware, hardware, or any combination thereof. The term "article of manufacture" as used herein refers to code or logic implemented in hardware or computer readable media such as optical storage devices, and volatile or non-volatile memory devices. Such hardware may include, but is not limited to, field programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), complex programmable logic devices (CPLDs), programmable logic arrays (PLAs), microprocessors, or other similar processing devices.

[0135] Embodiments of the invention described herein can include any of a number of different software, hardware, firmware, electronic circuits, controllers, computers (including hand-held computing devices), microchips, integrated circuits, printed circuit boards, and/or other microelectronic component known or described herein, or combinations thereof, and methods related thereto, suitable to provide the functionality described herein. Additionally, the functionality described herein for managing a capacitor system can be provided through any suitable electronic, mechanical, pneumatic, hydraulic, and/or other components and/or systems, or combinations thereof, or methods related thereto.

[0136] The previous description of the disclosed implementations is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these implementations will be readily apparent to those

skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the implementations shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[0137] While the above description has pointed out novel features of the invention as applied to various embodiments, the skilled person will understand that various omissions, substitutions, and changes in the form and details of the device or process illustrated may be made without departing from the scope of the invention.

What is claimed is:

1. An energy storage device, comprising:

an energy storage device housing comprising:

- a battery housing portion;
- a capacitor housing portion; and
- a housing lid configured to cover the battery housing portion and the capacitor housing portion;

a battery disposed within the battery housing portion, the battery comprising a first battery terminal extending through a battery lid enclosing the battery housing portion;

a capacitor disposed within the capacitor housing portion and connected in parallel with the battery, the capacitor comprising a first capacitor terminal;

a first bus bar electrically connecting the first battery terminal and the first capacitor terminal;

a first external device terminal extending through the energy storage device housing and configured to electrically connect to the first battery terminal and the bus bar.

2. The energy storage device of claim 1, wherein the first external device terminal comprises a stud configured to extend through an opening in the housing lid, through an opening in the first bus bar, and into a first opening in the battery terminal.

3. The energy storage device of claim 1, wherein the battery housing portion and capacitor housing portion are horizontally adjacent with respect to each other.

4. The energy storage device of claim 3, wherein the first bus bar extends across a portion of the battery lid, and between the battery lid and the housing lid, to the first capacitor terminal.

5. The energy storage device of claim 4, further comprising a second capacitor terminal, a second battery terminal, a second external device terminal and a second bus bar, wherein the second bus bar extends across a portion of the battery lid, and between the battery lid and the housing lid, to electrically connect the second battery terminal to the second capacitor terminal.

6. The energy storage device of claim 5, wherein the second bus bar extends between the capacitor bank and the housing lid, from the second capacitor terminal to the second device terminal.

7. The energy storage device of claim 6, wherein the first and the second bus bars each comprise a horizontally extending portion connected to the first and second battery terminals, and a vertically extending portion connected to the first and second capacitor terminals, respectively.

8. The energy storage device of claim 1, wherein the bus bar comprises a flexible bus bar configured to flex in response to relative movement between the capacitor and the battery.

9. A method of manufacturing a combined battery/capacitor energy storage device, comprising:

providing an energy storage device housing comprising a battery housing portion, a capacitor housing portion, and a housing lid configured to cover the battery housing portion and the capacitor housing portion;

providing a battery within the battery housing portion, the battery comprising a first battery terminal extending through a battery lid enclosing the battery housing portion;

inserting a capacitor into the capacitor housing portion, the capacitor comprising a first capacitor terminal;

connecting a first bus bar to the first battery terminal and the first capacitor terminal;

extending a first external device terminal through the energy storage device housing; and

electrically connecting the first external device terminal to the first battery terminal and the bus bar.

10. The method of claim **9**, wherein the first external device terminal comprises a stud, and wherein extending comprises extending the stud through an opening in the housing lid, through an opening in the first bus bar, and into a first opening in the battery terminal.

11. The method of claim **9**, wherein electrically connecting the first bus bar comprises extending the first bus bar across a portion of the battery lid, and between the battery lid and the housing lid, to the first capacitor terminal.

12. The method of claim **11**, further comprising electrically connecting a second capacitor terminal and a second battery terminal with a second bus bar, by extending the second bus bar across a portion of the battery lid, and between the battery lid and the housing lid.

13. The method of claim **12**, wherein the second bus bar extends between the capacitor bank and the housing lid, from the second capacitor terminal to a second device terminal.

14. The method of claim **13**, wherein the first and the second bus bars each comprise a horizontally extending portion connected to the first and second battery terminals, and a vertically extending portion connected to the first and second capacitor terminals, respectively.

15. The method of claim **9**, wherein the bus bar comprises a flexible bus bar configured to flex in response to relative movement between the capacitor and the battery.

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