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(71) Applicant: **CHEVRON U.S.A. INC.** [US/US]; 6001 Bollinger Canyon Road, San Ramon, CA 94583-0806 (US).

(72) Inventors: **BAMFORD, Benjamin**; 6001 Bollinger Canyon Road, San Ramon, CA 94583-0806 (US). **BERGERON, Henry**; 6001 Bollinger Canyon Road, San Ramon, CA 94583-0806 (US).

(74) Agent: **NEUFELD, Robert, T.**; King & Spalding, 1180 Peachtree St., Atlanta, GA 30309 (US).

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(54) Title: SUBSEA BATTERY SYSTEMS

(57) Abstract: A battery system is described herein. The battery system can include a number of first battery modules, where each first battery module of the plurality of first battery modules comprises a housing and a first coupling feature disposed on the housing, where the housing is rated for subsea conditions. The battery system can also include a first busbar having a number of second coupling features, where the first coupling feature of each first battery module is removably coupled to a second coupling feature of the first busbar. The first busbar can electrically couple to each first battery module when the first coupling feature is coupled to the second coupling feature. Each first battery module can deliver stored power to the first busbar through the first coupling feature and the second coupling feature.

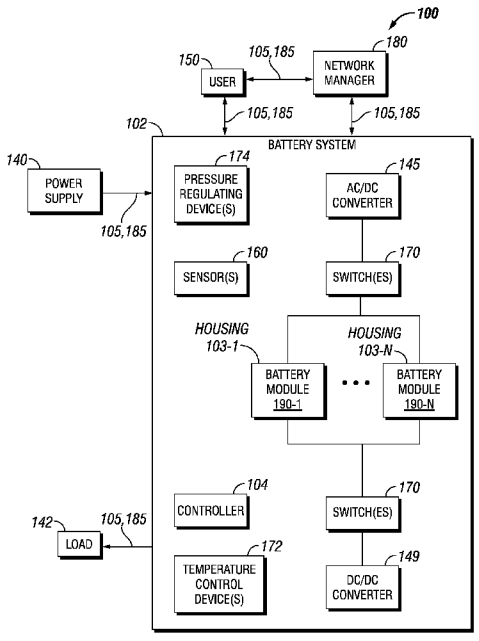


FIG. 1A

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SUBSEA BATTERY SYSTEMS

TECHNICAL FIELD

[0001] The present disclosure relates generally to subsea field operations, and more specifically to battery systems for use subsea.

BACKGROUND

[0002] In subterranean field operations, including in a subsea environment, one or more pieces of equipment operate using electricity. Because of the great distance (often thousands of feet) between the operation platform and the equipment, providing safe and reliable electricity to the equipment can be difficult and expensive.

SUMMARY

[0003] In general, in one aspect, the disclosure relates to a battery system for use in a subsea field operation. The battery system can include a number of first battery modules, where each first battery module includes a housing and a first coupling feature disposed on the housing, where the housing is rated for subsea conditions. The battery system can also include a first busbar having a number of second coupling features, where the first coupling feature of each first battery module is removably coupled to a second coupling feature of the first busbar. The first busbar can be electrically coupled to each first battery module when the first coupling feature is coupled to the second coupling feature, where each first battery module delivers stored power to the first busbar through the first coupling feature and the second coupling feature.

[0004] In another aspect, the disclosure can generally relate to mudline closure device for use in a subsea field operation. The mudline closure device can include a power supply, and a load used for disconnecting wellbore equipment from surface equipment. The mudline closure device can also include a battery system coupled to the power supply and the load. The battery system can include a number of battery modules, where each battery module includes a housing and a first coupling feature disposed on the housing, where the housing is rated for subsea conditions. The battery system can also include a busbar having a number of second coupling features, where the first coupling feature of each battery module is removably coupled to a second coupling feature of the busbar. The busbar can be electrically coupled to each battery module when the first

coupling feature is coupled to the second coupling feature, and where each battery module delivers stored power to the load through the first coupling feature, the second coupling feature, and the busbar.

[0005] These and other aspects, objects, features, and embodiments will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The drawings illustrate only example embodiments of methods, systems, and devices for a subsea battery system and are therefore not to be considered limiting of its scope, as subsea battery systems may admit to other equally effective embodiments. The elements and features shown in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the example embodiments. Additionally, certain dimensions or positionings may be exaggerated to help visually convey such principles. In the drawings, reference numerals designate like or corresponding, but not necessarily identical, elements.

[0007] Figures 1A and 1B show a diagram of a system that includes a battery system in accordance with certain example embodiments.

[0008] Figure 2 shows a computing device in accordance with certain example embodiments.

[0009] Figure 3 shows a block diagram of a system in accordance with certain example embodiments.

[0010] Figure 4 shows a subassembly that includes a battery system in accordance with certain example embodiments.

[0011] Figures 5A-5C show various views of another subassembly that includes a battery system in accordance with certain example embodiments.

[0012] Figures 6A and 6B show various views of a battery system in accordance with certain example embodiments.

[0013] Figures 7A-7F show various views of a battery module in accordance with certain example embodiments.

[0014] Figure 8 shows a locking bar in accordance with certain example embodiments.

[0015] Figures 9A-10B show various views of a portion of a battery system in accordance with certain example embodiments.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0016] The example embodiments discussed herein are directed to systems, apparatuses, and methods of subsea battery systems. While the example subsea battery systems described herein are directed toward subsea field operations, example subsea battery systems are not limited to subsea field operations. Examples of other applications that can be used with example subsea battery systems can include, but are not limited to, land-based field operations, above sea-level operations, and industrial operations.

[0017] A user as described herein may be any person that is involved with subsea battery systems. Examples of a user may include, but are not limited to, a crane operator, a roughneck, a company representative, a drilling engineer, a tool pusher, a service hand, a field engineer, an electrician, a mechanic, an operator, a consultant, a contractor, and a manufacturer's representative. The subsea battery systems (or components thereof) described herein can be made of one or more of a number of suitable materials to allow the subsea battery systems to meet certain standards and/or regulations while also maintaining durability in light of the one or more conditions (e.g., marine, high pressure, low temperature) under which the subsea battery systems can be exposed. Examples of such materials can include, but are not limited to, aluminum, stainless steel, fiberglass, glass, plastic, ceramic, and rubber.

[0018] Any portions of example subsea battery systems described herein can be made from a single piece (as from a mold). When an example subsea battery systems or portion thereof is made from a single piece, the single piece can be cut out, bent, stamped, and/or otherwise shaped to create certain features, elements, or other portions of a component. Alternatively, an example subsea battery systems (or portions thereof) can be made from multiple pieces that are mechanically coupled to each other. In such a case, the multiple pieces can be mechanically coupled to each other using one or more of a number of coupling methods, including but not limited to adhesives, welding, fastening devices, compression fittings, mating threads, and slotted fittings. One or more pieces that are mechanically coupled to each other can be coupled to each other in one or more of a number of ways, including but not limited to fixedly, hingedly, removeably, slidably, and threadably.

[0019] Components and/or features described herein can include elements that are described as coupling, fastening, securing, or other similar terms. Such terms are merely meant to distinguish various elements and/or features within a component or device and

are not meant to limit the capability or function of that particular element and/or feature. For example, a feature described as a "coupling feature" can couple, secure, fasten, and/or perform other functions aside from merely coupling. In addition, each component and/or feature described herein (including each component of an example battery system) can be made of one or more of a number of suitable materials, including but not limited to metal, ceramic, rubber, and plastic.

[0020] A coupling feature (including a complementary coupling feature) as described herein can allow one or more components and/or portions of an example subsea battery systems to become mechanically coupled, directly or indirectly, to another portion of the subsea battery systems. A coupling feature can include, but is not limited to, a portion of a hinge, an aperture, a recessed area, a protrusion, a slot, a spring clip, a male connector end, a female connector end, a tab, a detent, and mating threads. One portion of an example subsea battery system can be coupled to another portion of a subsea battery system by the direct use of one or more coupling features.

[0021] In addition, or in the alternative, a portion of an example subsea battery system can be coupled to another portion of the subsea battery system using one or more independent devices that interact with one or more coupling features disposed on a component of the subsea battery system. Examples of such devices can include, but are not limited to, a pin, a male connector end, a female connector end, a hinge, a fastening device (*e.g.*, a bolt, a screw, a rivet), and a spring. One coupling feature described herein can be the same as, or different than, one or more other coupling features described herein. A complementary coupling feature as described herein can be a coupling feature that mechanically couples, directly or indirectly, with another coupling feature.

[0022] If a component of a figure is described but not expressly shown or labeled in that figure, the label used for a corresponding component in another figure can be inferred to that component. Conversely, if a component in a figure is labeled but not described, the description for such component can be substantially the same as the description for the corresponding component in another figure. The numbering scheme for the various components in the figures herein is such that each component is a three digit number and corresponding components in other figures have the identical last two digits.

[0023] In addition, a statement that a particular embodiment (e.g., as shown in a figure herein) does not have a particular feature or component does not mean, unless

expressly stated, that such embodiment is not capable of having such feature or component. For example, for purposes of present or future claims herein, a feature or component that is described as not being included in an example embodiment shown in one or more particular drawings is capable of being included in one or more claims that correspond to such one or more particular drawings herein.

[0024] In the foregoing figures showing example embodiments of subsea battery systems, one or more of the components shown may be omitted, repeated, and/or substituted. Accordingly, example embodiments of subsea battery systems should not be considered limited to the specific arrangements of components shown in any of the figures. For example, features shown in one or more figures or described with respect to one embodiment can be applied to another embodiment associated with a different figure or description.

[0025] Example embodiments of subsea battery systems are described more fully hereinafter with reference to the accompanying drawings, in which example embodiments of subsea battery systems are shown. Subsea battery systems may, however, be embodied in many different forms and should not be construed as limited to the example embodiments set forth herein. Rather, these example embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of subsea battery systems to those of ordinary skill in the art. Like, but not necessarily the same, elements (also sometimes called components) in the various figures are denoted by like reference numerals for consistency.

[0026] Terms such as “first,” “second,” “top,” “bottom,” “proximal”, “distal”, “inner,” “outer,” “front”, “rear”, and “side” are used merely to distinguish one component (or part of a component or state of a component) from another. Such terms are not meant to denote a preference or a particular orientation, and are not meant to limit embodiments of subsea battery systems. In the following detailed description of the example embodiments, numerous specific details are set forth in order to provide a more thorough understanding of the invention. However, it will be apparent to one of ordinary skill in the art that the invention may be practiced without these specific details. In other instances, well-known features have not been described in detail to avoid unnecessarily complicating the description.

[0027] Figures 1A and 1B show a diagram of a subsea system 100 that includes a battery system 102 in accordance with certain example embodiments. Specifically, Figure

1A shows the subsea system 100, and Figure 1B shows a detailed system diagram of a controller 104 (also called a battery management system 104 or a BMS 104 herein). As shown in Figures 1A and 1B, the subsea system 100 can include a power supply 140, a load 142, a user 150, a network manager 180, and at least one battery system 102. In addition to the controller 104, the battery system 102 can include one or more sensors 160 (also sometimes called sensor modules 160 or sensor devices 160), one or more switches 170, one or more temperature control devices 172, one or more pressure regulating devices 174, one or more battery modules 190 (e.g., battery module 190-1, battery module 190-N), one or more alternating current (AC)-to-direct current (DC) converters 145 (also called, for example, AC/DC converters 145), and one or more DC/DC converters 149.

[0028] As shown in Figure 1B, the controller 104 can include one or more of a number of components. Such components, can include, but are not limited to, a control engine 106, a communication module 108, a timer 110, an energy metering module 111, a power module 112, a storage repository 130, a hardware processor 120, a memory 122, a transceiver 124, an application interface 126, and, optionally, a security module 128. The components shown in Figures 1A and 1B are not exhaustive, and in some embodiments, one or more of the components shown in Figures 1A and 1B may not be included in an example subsea system.

[0029] Further, one or more components shown in Figures 1A and 1B can be rearranged. For example, one or more of the switches 170 can be part of the controller 104 of Figure 1B. Alternatively, the switches 170 can be separate components from the controller 104 that are controlled by the controller 104. As another example, there can be multiple local controllers 104 that are part of one or more of the battery modules 190 and perform at least a portion of the functions of the controller 104, as described below. Any component of the example battery system 102 can be discrete or combined with one or more other components of the battery system 102.

[0030] A user 150 may be any person that interacts with subsea systems or other devices that use example battery systems. Examples of a user 150 may include, but are not limited to, an engineer, a company representative, an electrician, an instrumentation and controls technician, a mechanic, an operator, a consultant, an inventory management system, an inventory manager, a foreman, a labor scheduling system, a contractor, and a manufacturer's representative. The user 150 can use a user system (not shown), which may include a display (*e.g.*, a GUI). The user 150 interacts with (*e.g.*, sends data to,

receives data from) the controller 104 (including portions thereof) of the battery system 102 via the application interface 126 (described below). The user 150 can also interact with a network manager 180, the power supply 140, and the load 142. Interaction between the user 150 and the battery system 102, the network manager 180, the power supply 140, and the load 142 can be conducted using signal transfer links 105 and/or power transfer links 185.

[0031] Each signal transfer link 105 and each power transfer link 185 can include wired (*e.g.*, Class 1 electrical cables, Class 2 electrical cables, electrical connectors, electrical conductors, electrical traces on a circuit board, power line carrier, RS485) and/or wireless (*e.g.*, Wi-Fi, visible light communication, cellular networking, Bluetooth, WirelessHART, ISA100) technology. For example, a signal transfer link 105 can be (or include) one or more electrical conductors that are coupled to the battery system 102 and to a sensor 160. A signal transfer link 105 can transmit signals (*e.g.*, communication signals, control signals, data) between the battery system 102 and the user 150, the network manager 180, the power supply 140, and the load 142. Similarly, a power transfer link 185 can transmit power between the battery system 102 and the user 150, the network manager 180, the power supply 140, and the load 142.

[0032] In some cases, a signal transfer link 105 and a power transfer link 185 can be or use the same wired and/or wireless equipment. One or more signal transfer links 105 and/or one or more power transfer links 185 can also transmit signals and power, respectively, between components (e.g., controller 104, sensor 160, switch 170) of the battery system 102.

[0033] The network manager 180 is a device or component that can communicate with the battery system 102. For example, the network manager 180 can send instructions to the controller 104 of the battery system 102 as to when certain switches 170 should be operated (change state). As another example, the network manager 180 can receive data (e.g., run time, current flow) associated with the operation of each battery module 190 of the battery system 102 to determine when maintenance should be performed on the battery system 102 or portions thereof.

[0034] The one or more sensors 160 can be any type of sensing device that measure one or more parameters. Examples of types of sensors 160 can include, but are not limited to, a resistor, a Hall Effect current sensor, a thermistor, a vibration sensor, an accelerometer, a passive infrared sensor, a photocell, a pressure sensor, a thermometer,

and a resistance temperature detector. A parameter that can be measured by a sensor 160 can include, but is not limited to, current, voltage, power, resistance, vibration, position, pressure, acceleration, and temperature. In some cases, the parameter or parameters measured by a sensor 160 can be used to operate one or more battery modules 190 of the battery system 102. Each sensor 160 can use one or more of a number of communication protocols. A sensor 160 can be associated with the battery system 102 in the system 100. A sensor 160 can be located within the housing 103 (e.g., housing 103-1, housing 103-N) of one or more battery modules 190 of the battery system 102, disposed on the housing 103 of a battery module 190, or located outside the housing 103 of the battery module 190.

[0035] The user 150, the network manager 180, the power supply 140, and/or the load 142 can interact with the controller 104 of the battery system 102 using the application interface 126 in accordance with one or more example embodiments. Specifically, the application interface 126 of the controller 104 receives data (*e.g.*, information, communications, instructions, updates to firmware) from and sends data (*e.g.*, information, communications, instructions) to the user 150, the network manager 180, the power supply 140, and/or the load 142. The user 150, the network manager 180, the power supply 140, and/or the load 142 can include an interface to receive data from and send data to the controller 104 in certain example embodiments. Examples of such an interface can include, but are not limited to, a graphical user interface, a touchscreen, an application programming interface, a keyboard, a monitor, a mouse, a web service, a data protocol adapter, some other hardware and/or software, or any suitable combination thereof.

[0036] The controller 104, the user 150, the network manager 180, the power supply 140, and/or the load 142 can use their own system or share a system in certain example embodiments. Such a system can be, or contain a form of, an Internet-based or an intranet-based computer system that is capable of communicating with various software. A computer system includes any type of computing device and/or communication device, including but not limited to the controller 104. Examples of such a system can include, but are not limited to, a desktop computer with LAN, WAN, Internet or intranet access, a laptop computer with LAN, WAN, Internet or intranet access, a smart phone, a server, a server farm, an android device (or equivalent), a tablet, smartphones, and a personal digital assistant (PDA). Such a system can correspond to a computer system as described below with regard to Figure 2.

[0037] Further, as discussed above, such a system can have corresponding software (*e.g.*, user software, controller software, network manager software). The software can execute on the same or a separate device (*e.g.*, a server, mainframe, desktop personal computer (PC), laptop, PDA, television, cable box, satellite box, kiosk, telephone, mobile phone, or other computing devices) and can be coupled by the communication network (*e.g.*, Internet, Intranet, Extranet, Local Area Network (LAN), Wide Area Network (WAN), or other network communication methods) and/or communication channels, with wire and/or wireless segments according to some example embodiments. The software of one system can be a part of, or operate separately but in conjunction with, the software of another system within the system 100.

[0038] As discussed above, each battery module 190 of the battery system 102 can include a housing 103. The housing 103 can include at least one wall that forms a cavity. Similarly, one or more other components (e.g., the controller 104, switches 170) of the battery system 102 can be disposed within or on a housing, which can be the same as or different than a housing 103 of a battery module 190. In some cases, a housing (e.g., housing 103-1) of the battery system 102 can be designed to comply with any applicable standards so that the battery system 102 (or portions thereof) can be located in a particular environment (*e.g.*, subsea, marine).

[0039] The housing 103 of the battery system 102 can be used to house one or more components of the battery system 102, including one or more components of the controller 104. As discussed above, the controller 104 in this example includes the control engine 106, the communication module 108, the timer 110, the energy metering module 111, the power module 112, the storage repository 130, the hardware processor 120, the memory 122, the transceiver 124, the application interface 126, and the optional security module 128. In alternative embodiments, any one or more of these or other components of the battery system 102 can be disposed on a housing (e.g., housing 103-1) and/or remotely from the housing.

[0040] The storage repository 130 can be a persistent storage device (or set of devices) that stores software and data used to assist the controller 104 in communicating with the user 150, the network manager 180, the power supply 140, and/or the load 142 within the system 100. In one or more example embodiments, the storage repository 130 stores one or more protocols 132, algorithms 133, and stored data 134. The protocols 132 can be any of a number of protocols that are used to send and/or receive data between the

controller 104 and the user 150, the network manager 180, and one or more sensors 160. The protocols 132 can also include processes and procedures that are not related to communications. For example, a protocol 132 can include a process for detecting, attempting to correct, and reporting a failure of a battery module 190.

[0041] When a protocol 132 is used for communications, the protocol 132 can be used for wired and/or wireless communication. Examples of a protocol 132 can include, but are not limited to, Modbus, PROFIBUS, PROFINET, and Ethernet (for example, when data packets are transmitted over copper or fiber optic physical media). One or more of the protocols 132 can be a time-synchronized protocol. Examples of such time-synchronized protocols can include, but are not limited to, a highway addressable remote transducer (HART) protocol, a wireless HART protocol, and an International Society of Automation (ISA) 100 protocol. In this way, one or more of the protocols 132 can provide a layer of security to the data transferred within the system 100.

[0042] The algorithms 133 can be any procedures (e.g., a series of method steps), formulas, logic steps, mathematical models, and/or other similar operational procedures that the control engine 106 of the controller 104 follows based on certain conditions at a point in time. An example of an algorithm 133 is measuring (using the energy metering module 111), storing (using the stored data 134 in the storage repository 130), and evaluating over time the current and voltage the power supply 140 delivers to the AC/DC converter 145 and the AC/DC converter 145 delivers to a battery module 190.

[0043] As another example, an algorithm 133 can be directed to continuously monitor the current (as measured by the energy metering module 111 and stored as stored data 134) output by each battery module 190. As another example, an algorithm 133 can be directed to analyzing the stored power output by each battery module 190 of the power supply 140 over time. If a stored power output exceeds a threshold value, then one or more switches 170 can change state (e.g., using the control engine 106) to electrically isolate the battery module 190. Alternatively, a protocol 132 can be used to direct the control engine 106 to operate one or more of the switches 170 based on some other factor, including but not limited to a passage of time.

[0044] Stored data 134 can be any data associated with the battery system 102 (including any components thereof), any measurements taken by the sensors 160, measurements taken by the energy metering module 111, time measured by the timer 110, threshold values, current ratings for the power supply 140, results of previously run or

calculated algorithms, nameplate data of each battery module 190, and/or any other suitable data. Such data can be any type of data, including but not limited to historical data for the battery system 102 (including any components thereof), performance of the temperature control devices 172, performance of the pressure regulating devices 174, calculations, measurements taken by the energy metering module 111, and measurements taken by one or more sensors 160. The stored data 134 can be associated with some measurement of time derived, for example, from the timer 110.

[0045] Examples of a storage repository 130 can include, but are not limited to, a database (or a number of databases), a file system, a hard drive, flash memory, some other form of solid state data storage, or any suitable combination thereof. The storage repository 130 can be located on multiple physical machines, each storing all or a portion of the protocols 132, the algorithms 133, and/or the stored data 134 according to some example embodiments. Each storage unit or device can be physically located in the same or in a different geographic location.

[0046] The storage repository 130 can be operatively connected to the control engine 106. In one or more example embodiments, the control engine 106 includes functionality to communicate with the user 150, the network manager 180, the power supply 140, and the load 142 in the system 100. More specifically, the control engine 106 sends information to and/or receives information from the storage repository 130 in order to communicate with the user 150, the network manager 180, the power supply 140, and the load 142. As discussed below, the storage repository 130 can also be operatively connected to the communication module 108 in certain example embodiments.

[0047] In certain example embodiments, the control engine 106 of the controller 104 controls the operation of one or more components (*e.g.,* the communication module 108, the timer 110, the transceiver 124) of the controller 104 and/or one or more components (e.g., temperature control devices 172, pressure regulating devices 174) of another portion of the battery system 102. For example, the control engine 106 can activate the communication module 108 when the communication module 108 is in "sleep" mode and when the communication module 108 is needed to send data received from another component (*e.g.*, switches 170, a sensor 160, the user 150) in the system 100.

[0048] As another example, the control engine 106 can acquire the current time using the timer 110. The timer 110 can enable the controller 104 to control the battery system 102 (including any components thereof, such as one or more power supplies 140

and one or more switches 170) even when the controller 104 has no communication with the network manager 180. As yet another example, the control engine 106 can direct the energy metering module 111 to measure and send power consumption information of a power supply 140 to the network manager 180. In some cases, the control engine 106 of the controller 104 can control the position (e.g., open, closed) of each switch 170 within the battery system 102.

[0049] The control engine 106 can be configured to perform a number of functions that control which battery module 190 of the battery system 102 receives power from the power supply 140 and which battery module 190 of the battery system 102 provides power to the load 142 system 100. Specifically, the control engine 106 can control the position of each of the switches 170, thereby controlling which particular battery modules 190 of the battery system 102 become isolated, which battery module 190 receive power from the power supply 140 to generate stored power, and/or which battery module 190 release stored power to the load 142 at a particular point in time.

[0050] For example, the control engine 106 can execute any of the protocols 132 and/or algorithms 133 stored in the storage repository 130 and use the results of those protocols 132 and/or algorithms 133 to change the position of one or more switches 170. As a specific example, the control engine 106 can measure (using the energy metering module 111), store (as stored data 134 in the storage repository 130), and evaluate, using an algorithm 133, the stored power delivered by each battery module 190 of the battery system 102 to the load 142 over time. In this way, the operation of each battery module 190 of the battery system 102 can be optimized to increase the reliability of the battery modules 190.

[0051] As another specific example, the control engine 106 can determine, based on measurements made by the energy metering module 111, whether a particular battery module 190 (or some other component) of the battery system 102 has failed. In such a case, the control engine 106 can change the position of one or more switches 170 to have another battery module of the battery system 102 provide power to the load that was receiving power from the battery module of the battery system 102 that failed.

[0052] The control engine 106 can control the operation of one or more sensors 160 in the battery system 102. The control engine 106 can also use the measurements taken by the sensors 160 to control the operation of one or more components (e.g., a

temperature control device 172, a pressure regulating device 174, a switch 170) of the battery system 102 at a particular point in time.

[0053] The control engine 106 can generate an alarm when an operating parameter (e.g., total number of operating hours, number of consecutive operating hours, number of operating hours delivering power above a current level, input power quality, vibration, operating ambient temperature, operating temperature) of the battery system 102 (or component thereof) exceeds a threshold value, indicating possible present or future failure of the battery system 102 (or component thereof). The control engine 106 can further measure (using one or more sensors 160) and analyze any of a number of power (e.g., current, voltage, surges, faults, storage time, discharge time) associated with the battery modules 190 over time. Using one or more algorithms 133, the control engine 106 can predict the expected useful life of the battery modules (or other components of the battery system 102) based on stored data 134, a protocol 132, one or more threshold values, and/or some other factor. The control engine 106 can also measure (using one or more sensors 160) and analyze the efficiency of the battery system 102 (or component thereof) over time. An alarm can be generated by the control engine 106 when the efficiency of the battery system 102 (or component thereof) falls below a threshold value, indicating failure of the battery system 102 (or component thereof).

[0054] In certain example embodiments, the control engine 106 can regulate the temperature and/or pressure of a battery module 190 and/or any other component of the battery system 102. For example, the control engine 106 can determine (based on a measurement made by a sensor 160 that measures temperature) whether to activate a heating circuit (a type of temperature control device 172) when the temperature exceeds a high temperature threshold value. As another example, the control engine 106 can determine (based on a measurement made by a sensor 160 that measures temperature) whether to activate a cooling circuit (another type of temperature control device 172) when the temperature falls below a low temperature threshold value. As yet another example, the control engine 106 can determine (based on a measurement made by a sensor 160 that measures pressure) whether to activate a pressure regulating device 174 when the pressure falls outside of a range of acceptable pressure values.

[0055] The control engine 106 can provide power, control, communication, and/or other similar signals to the user 150, the network manager 180, the power supply 140, and the load 142. Similarly, the control engine 106 can receive power, control,

communication, and/or other similar signals from the user 150, the network manager 180, the power supply 140, and the load 142. The control engine 106 can control each sensor 160 automatically (for example, based on one or more algorithms 133 stored in the storage repository 130) and/or based on power, control, communication, and/or other similar signals received from another device through a signal transfer link 105 and/or a power transfer link 185. The control engine 106 may include a printed circuit board, upon which the hardware processor 120 and/or one or more discrete components of the controller 104 are positioned.

[0056] In certain embodiments, the control engine 106 of the controller 104 can communicate with one or more components of a system external to the system 100 in furtherance of optimizing the performance of the battery modules 190 of the battery system 102. For example, the control engine 106 can interact with an inventory management system by ordering a component (e.g., a DC/DC converter 149, battery module 190) of the battery system 102 to replace a component of the battery system 102 that the control engine 106 has determined to fail or be failing. As another example, the control engine 106 can interact with a workforce scheduling system by scheduling a maintenance crew to repair or replace the battery system 102 (or component thereof) when the control engine 106 determines that the battery system 102 (or component thereof) requires maintenance or replacement. In this way, the controller 104 is capable of performing a number of functions beyond what could reasonably be considered a routine task.

[0057] In certain example embodiments, the control engine 106 can include an interface that enables the control engine 106 to communicate with one or more components (*e.g.*, a pressure regulating device 174, a switch 170) of the battery system 102. For example, if the battery system 102 operates under IEC Standard 62386, then the battery system 102 can have a serial communication interface that will transfer data (e.g., stored data 134) measured by the sensors 160. In such a case, the control engine 106 can also include a serial interface to enable communication with one or more components within the battery system 102. Such an interface can operate in conjunction with, or independently of, the protocols 132 used to communicate between the controller 104 and the user 150, the network manager 180, the power supply 140, and the load 142.

[0058] The control engine 106 (or other components of the controller 104) can also include one or more hardware components and/or software elements to perform its

functions. Such components can include, but are not limited to, a universal asynchronous receiver/transmitter (UART), a serial peripheral interface (SPI), a direct-attached capacity (DAC) storage device, an analog-to-digital converter, an inter-integrated circuit (I^2C), and a pulse width modulator (PWM).

[0059] The communication module 108 of the controller 104 determines and implements the communication protocol (*e.g.*, from the protocols 132 of the storage repository 130) that is used when the control engine 106 communicates with (*e.g.*, sends signals to, receives signals from) the user 150, the network manager 180, the power supply 140, and/or the load 142. In some cases, the communication module 108 accesses the stored data 134 to determine which communication protocol 132 is used to communicate with the sensor 160 associated with the stored data 134. In addition, the communication module 108 can interpret the communication protocol 132 of a communication received by the controller 104 so that the control engine 106 can interpret the communication.

[0060] The communication module 108 can send and receive data between the network manager 180, power supply 140, the load 142, and/or the users 150 and the controller 104. The communication module 108 can send and/or receive data in a given format that follows a particular protocol 132. The control engine 106 can interpret the data packet received from the communication module 108 using the protocol information stored in the storage repository 130. The control engine 106 can also facilitate the data transfer between one or more sensors 160 and the network manager 180, the power supply 140, the load 142, and/or a user 150 by converting the data into a format understood by the communication module 108.

[0061] The communication module 108 can send data (*e.g.*, protocols 132, algorithms 133, stored data 134, operational information, alarms) directly to and/or retrieve data directly from the storage repository 130. Alternatively, the control engine 106 can facilitate the transfer of data between the communication module 108 and the storage repository 130. The communication module 108 can also provide encryption to data that is sent by the controller 104 and decryption to data that is received by the controller 104. The communication module 108 can also provide one or more of a number of other services with respect to data sent from and received by the controller 104. Such services can include, but are not limited to, data packet routing information and procedures to follow in the event of data interruption.

[0062] The timer 110 of the controller 104 can track clock time, intervals of time, an amount of time, and/or any other measure of time. The timer 110 can also count the number of occurrences of an event, whether with or without respect to time. Alternatively, the control engine 106 can perform the counting function. The timer 110 is able to track multiple time measurements concurrently. The timer 110 can track time periods based on an instruction received from the control engine 106, based on an instruction received from the user 150, based on an instruction programmed in the software for the controller 104, based on some other condition or from some other component, or from any combination thereof.

[0063] The timer 110 can be configured to track time when there is no power delivered to the controller 104 (e.g., the power module 112 malfunctions) using, for example, a super capacitor or a battery backup. In such a case, when there is a resumption of power delivery to the controller 104, the timer 110 can communicate any aspect of time to the controller 104. In such a case, the timer 110 can include one or more of a number of components (e.g., a super capacitor, an integrated circuit) to perform these functions.

[0064] The energy metering module 111 of the controller 104 measures one or more components of power (e.g., current, voltage, resistance, VARs, watts) at one or more points (e.g., output of each DC/DC converter 149 of the power supply 140, voltage across each cell of a battery module 190, current out of a battery module 190) associated with the battery system 102. The energy metering module 111 can include any of a number of measuring devices and related devices, including but not limited to a voltmeter, an ammeter, a power meter, an ohmmeter, a current transformer, a potential transformer, and electrical wiring. The energy metering module 111 can measure a component of power continuously, periodically, based on the occurrence of an event, based on a command received from the control module 106, and/or based on some other factor.

[0065] The power module 112 of the controller 104 provides power to one or more other components (*e.g.*, timer 110, control engine 106) of the controller 104. In addition, in certain example embodiments, the power module 112 can provide power to one or more other components (e.g. a sensor 160) of the battery system 102. The power module 112 can include one or more of a number of single or multiple discrete components (*e.g.*, transistor, diode, resistor), and/or a microprocessor. The power module 112 may include a printed circuit board, upon which the microprocessor and/or one or more discrete components are positioned. In some cases, the power module 112 can include one or more

components that allow the power module 112 to measure one or more elements of power (e.g., voltage, current) that is delivered to and/or sent from the power module 112. Alternatively, the controller 104 can include a power metering module (not shown) to measure one or more elements of power that flows into, out of, and/or within the controller 104.

[0066] The power module 112 can include one or more components (*e.g.*, a transformer, a diode bridge, an inverter, a converter) that receives power (for example, through an electrical cable) from a source external to the battery system 102 and generates power of a type (*e.g.*, AC, DC) and level (*e.g.*, 12V, 24V, 120V) that can be used by the other components of the controller 104 and/or the battery system 102. The power module 112 can use a closed control loop to maintain a preconfigured voltage or current with a tight tolerance at the output. The power module 112 can also protect the rest of the electronics (e.g., hardware processor 120, transceiver 124) in the battery system 102 from surges generated in the line.

[0067] In addition, or in the alternative, the power module 112 can be a source of power in itself to provide signals to the other components of the controller 104 and/or the battery system 102. For example, the power module 112 can be a battery. As another example, the power module 112 can be a localized photovoltaic power system. The power module 112 can also have sufficient isolation in the associated components of the power module 112 (e.g., transformers, opto-couplers, current and voltage limiting devices) so that the power module 112 is certified to provide power to an intrinsically safe circuit.

[0068] In certain example embodiments, the power module 112 of the controller 104 can also provide power and/or control signals, directly or indirectly, to one or more of the sensors 160. In such a case, the control engine 106 can direct the power generated by the power module 112 to the sensors 160 of the battery system 102. In this way, power can be conserved by sending power to the sensors 160 of the battery system 102 when those devices need power, as determined by the control engine 106.

[0069] The hardware processor 120 of the controller 104 executes software, algorithms, and firmware in accordance with one or more example embodiments. Specifically, the hardware processor 120 can execute software on the control engine 106 or any other portion of the controller 104, as well as software used by the user 150, the network manager 180, the power supply 140, and/or the load 142. The hardware processor 120 can be an integrated circuit, a central processing unit, a multi-core

processing chip, SoC, a multi-chip module including multiple multi-core processing chips, or other hardware processor in one or more example embodiments. The hardware processor 120 is known by other names, including but not limited to a computer processor, a microprocessor, and a multi-core processor.

[0070] In one or more example embodiments, the hardware processor 120 executes software instructions stored in memory 122. The memory 122 includes one or more cache memories, main memory, and/or any other suitable type of memory. The memory 122 can include volatile and/or non-volatile memory. The memory 122 is discretely located within the controller 104 relative to the hardware processor 120 according to some example embodiments. In certain configurations, the memory 122 can be integrated with the hardware processor 120.

[0071] In certain example embodiments, the controller 104 does not include a hardware processor 120. In such a case, the controller 104 can include, as an example, one or more field programmable gate arrays (FPGA) insulated-gate bipolar transistors (IGBTs), and/or one or more integrated circuits (ICs). Using FPGAs, IGBTs, ICs, and/or other similar devices known in the art allows the controller 104 (or portions thereof) to be programmable and function according to certain logic rules and thresholds without the use of a hardware processor. Alternatively, FPGAs, IGBTs, ICs, and/or similar devices can be used in conjunction with one or more hardware processors 120.

[0072] The transceiver 124 of the controller 104 can send and/or receive control and/or communication signals. Specifically, the transceiver 124 can be used to transfer data between the controller 104 and the user 150, the network manager 180, the power supply 140, and/or the load 142. The transceiver 124 can use wired and/or wireless technology. The transceiver 124 can be configured in such a way that the control and/or communication signals sent and/or received by the transceiver 124 can be received and/or sent by another transceiver that is part of the user 150, the network manager 180, the power supply 140, and/or the load 142. The transceiver 124 can use any of a number of signal types, including but not limited to radio signals.

[0073] When the transceiver 124 uses wireless technology, any type of wireless technology can be used by the transceiver 124 in sending and receiving signals. Such wireless technology can include, but is not limited to, Wi-Fi, visible light communication, cellular networking, and Bluetooth. The transceiver 124 can use one or more of any number of suitable communication protocols (*e.g.*, ISA100, HART) when sending and/or

receiving signals. Such communication protocols can be stored in the communication protocols 132 of the storage repository 130. Further, any transceiver information for the user 150, the network manager 180, the power supply 140, and/or the load 142 can be part of the stored data 134 (or similar areas) of the storage repository 130.

[0074] Optionally, in one or more example embodiments, the security module 128 secures interactions between the controller 104, the user 150, the network manager 180, the power supply 140, and/or the load 142. More specifically, the security module 128 authenticates communication from software based on security keys verifying the identity of the source of the communication. For example, user software may be associated with a security key enabling the software of the user 150 to interact with the controller 104 and/or the sensors 160. Further, the security module 128 can restrict receipt of information, requests for information, and/or access to information in some example embodiments.

[0075] The load 142 of the system 100 can include one or more of any number of devices and/or components that can be operated using a battery system 102. The system 100 can have one or more of any number and/or type of load 142. Examples of such a load 142 can include, but are not limited to, a local control module, a motor (as for a pump), an electrical conductor or electrical cable, a terminal block, an air moving device, a baffle, and a circuit board.

[0076] The power supply 140 provides power to the battery system 102. In particular, the power supply 140 provides power to the battery modules 190 so that the battery modules 190 can store the power as stored power. The power supply 140 can be substantially the same as, or different than, the power module 112 of the controller 104. The power supply 140 can include one or more of a number of single or multiple discrete components (*e.g.*, transistor, diode, resistor, IGBT, MOSFET), and/or a microprocessor. The power supply 140 may include a printed circuit board, upon which the microprocessor and/or one or more discrete components are positioned.

[0077] The power supply 140 may be controlled by the controller 104 such that a predefined charging current (e.g., a constant current, a variable current) profile can be maintained by varying the applied voltage. The power supply 140 may also provide a lower voltage (e.g., 24VDC) such that the controller 104 and associated sensors 160 and switches 170 can be powered off this supply. The power supply 140 can be remotely located relative to the rest of the battery system 102. In such a case, the power supply 140

can be located either in close proximity to the remainder of the battery system 102 or a significant distance (e.g., thousands of feet) from the remainder of the battery system 102.

[0078] In certain example embodiments, the power supply 140 can include one or more components (*e.g.*, a transformer, a diode bridge, an inverter, a converter) that generates and/or sends power (for example, through an electrical cable) to the AC/DC converter 145. The AC/DC converter 145 receives the power from the power supply 140 and generates power of a type (*e.g.*, AC, DC) and level (*e.g.*, 12V, 24V, 120V) that can be used by the controller 104 and/or the battery modules 190. In some cases, the power supply 140 can receive power from a source external to the battery system 102. In addition, or in the alternative, the power supply 140 can be a source of power in itself. For example, the power supply 140 can be a battery, a localized photovoltaic power system, or some other source of independent power.

[0079] As explained above, the power supply 140 can send power to one or more AC/DC converters 145. In some cases, the AC/DC converter 145 receives AC power from the power supply 140 and converts the AC power to raw DC power. The AC/DC converter 145 sends the raw DC power to one or more of the battery modules 190. When the battery modules 190 release their stored power, the stored power is sent to one or more DC/DC converters 149. When a DC/DC converter 149 receives the stored power from the battery modules 190, each DC/DC converter 149 converts the stored power to final DC power, which is used, directly or indirectly, by the load 142. In some cases, a DC/AC inverter can be disposed between one or more of the DC/DC converters 149 and the load 142 in the event that the load 142 (or portions thereof) uses AC power instead of DC power.

[0080] The one or more AC/DC converters 145 and the one or more DC/DC converters 149 can be located in the same housing or in multiple housings of the battery system 102. For example, a DC/DC converter 149 can be disposed in the housing 103 of each battery module 190. In certain example embodiments, each AC/DC converter 145 and/or each DC/DC converter 149 of the battery system 102 can be individually replaceable (modular) without having to replace the entire battery system 102. In addition, or in the alternative, one or more AC/DC converters 145 and one or more of the DC/DC converters 149 can be stand-alone devices. A DC/DC converter 149 can have one or more output channels, where each output channel is coupled to a portion of the load 142 to provide power to the load 142. Similarly, an AC/DC converter 145 can have one or more

input channels, where each input channel is coupled to one or more sources of power (e.g., power supply 140) to receive power from such one or more sources of power.

[0081] As shown in Figure 1A, each DC/DC converter 149 of the power supply 140 can be coupled to the load 142 to deliver stored power from the battery modules 190. In some cases, one or more switches 170 can be used to determine which battery module 190 and/or DC/DC converter 149 is coupled to the load 142 at any particular point in time. A switch 170 has an open state and a closed state (position). In the open state, the switch 170 creates an open circuit, which prevents a battery module 190 and/or a DC/DC converter 149 from delivering stored power to the load 142. In the closed state, the switch 170 creates a closed circuit, which allows a battery module 190 and/or a DC/DC converter 149 to deliver stored power to the load 142. In certain example embodiments, the position of each switch 170 is controlled by the control engine 106 of the controller 104.

[0082] Each switch 170 can be any type of device that changes state or position (e.g., opens, closes) based on certain conditions. Examples of a switch 170 can include, but are not limited to, a transistor, a dipole switch, a toggle switch, a relay contact, a resistor, and a NOR gate. In certain example embodiments, each switch 170 can operate (e.g., change from a closed position to an open position, change from an open position to a closed position) based on input from the controller 104.

[0083] In certain example embodiments, the one or more temperature control devices 172 control the temperature of the battery system 102 or portions thereof. A temperature control device 172 can take on one or more of a number of forms, including but not limited to a resistive heating circuit and a cooling loop. A temperature control device 172 can include one or more of a number of components. Such components can include, but are not limited to, a fan, a pump, a motor, a heat exchanger, and a heating element. A temperature control device 172 (or portions thereof) can be controlled by the control engine 106 of the controller 104.

[0084] In certain example embodiments, the one or more pressure regulating devices 174 control the pressure of the battery system 102 or portions thereof. A pressure regulating device 174 can include one or more of a number of components. Such components can include, but are not limited to, a pressure relief valve, a pressure regulating valve, fan, a pump, and a motor. A pressure regulating device 174 (or portions thereof) can be controlled by the control engine 106 of the controller 104.

[0085] As stated above, the battery system 102 can be placed in any of a number of environments. In such a case, the housing 103 of the battery system 102 (or components thereof) can be configured to comply with applicable standards for any of a number of environments. For example, the battery system 102 (or portions thereof) can be rated under applicable standards for marine and/or subsea environments.

[0086] Figure 2 illustrates one embodiment of a computing device 218 that implements one or more of the various techniques described herein, and which is representative, in whole or in part, of the elements described herein pursuant to certain exemplary embodiments. Computing device 218 is one example of a computing device and is not intended to suggest any limitation as to scope of use or functionality of the computing device and/or its possible architectures. Neither should computing device 218 be interpreted as having any dependency or requirement relating to any one or combination of components illustrated in the example computing device 218.

[0087] Computing device 218 includes one or more processors or processing units 214, one or more memory/storage components 215, one or more input/output (I/O) devices 216, and a bus 217 that allows the various components and devices to communicate with one another. Bus 217 represents one or more of any of several types of bus structures, including a memory bus or memory controller, a peripheral bus, an accelerated graphics port, and a processor or local bus using any of a variety of bus architectures. Bus 217 includes wired and/or wireless buses.

[0088] Memory/storage component 215 represents one or more computer storage media. Memory/storage component 215 includes volatile media (such as random access memory (RAM)) and/or nonvolatile media (such as read only memory (ROM), flash memory, optical disks, magnetic disks, and so forth). Memory/storage component 215 includes fixed media (*e.g.,* RAM, ROM, a fixed hard drive, etc.) as well as removable media (*e.g.,* a Flash memory drive, a removable hard drive, an optical disk, and so forth).

[0089] One or more I/O devices 216 allow a customer, utility, or other user to enter commands and information to computing device 218, and also allow information to be presented to the customer, utility, or other user and/or other components or devices. Examples of input devices include, but are not limited to, a keyboard, a cursor control device (*e.g.,* a mouse), a microphone, a touchscreen, and a scanner. Examples of output devices include, but are not limited to, a display device (*e.g.,* a monitor or projector), speakers, outputs to a lighting network (*e.g.*, DMX card), a printer, and a network card.

[0090] Various techniques are described herein in the general context of software or program modules. Generally, software includes routines, programs, objects, components, data structures, and so forth that perform particular tasks or implement particular abstract data types. An implementation of these modules and techniques are stored on or transmitted across some form of computer readable media. Computer readable media is any available non-transitory medium or non-transitory media that is accessible by a computing device. By way of example, and not limitation, computer readable media includes "computer storage media".

[0091] "Computer storage media" and "computer readable medium" include volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules, or other data. Computer storage media include, but are not limited to, computer recordable media such as RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which is used to store the desired information and which is accessible by a computer.

[0092] The computer device 218 is connected to a network (not shown) (*e.g.*, a local area network (LAN), a wide area network (WAN) such as the Internet, cloud, or any other similar type of network) via a network interface connection (not shown) according to some exemplary embodiments. Those skilled in the art will appreciate that many different types of computer systems exist (*e.g.*, desktop computer, a laptop computer, a personal media device, a mobile device, such as a cell phone or personal digital assistant, or any other computing system capable of executing computer readable instructions), and the aforementioned input and output means take other forms, now known or later developed, in other exemplary embodiments. Generally speaking, the computer system 218 includes at least the minimal processing, input, and/or output means necessary to practice one or more embodiments.

[0093] Further, those skilled in the art will appreciate that one or more elements of the aforementioned computer device 218 is located at a remote location and connected to the other elements over a network in certain exemplary embodiments. Further, one or more embodiments is implemented on a distributed system having one or more nodes, where each portion of the implementation (*e.g.*, control engine 106) is located on a

different node within the distributed system. In one or more embodiments, the node corresponds to a computer system. Alternatively, the node corresponds to a processor with associated physical memory in some exemplary embodiments. The node alternatively corresponds to a processor with shared memory and/or resources in some exemplary embodiments.

[0094] Figure 3 shows a block diagram of a system 300 in accordance with certain example embodiments. Referring to Figures 1A-3, the system 300 of Figure 3 includes a power supply 340, a load 342, and an example battery system 302 disposed therebetween. The power supply 340, the load 342, and the battery system 302 of Figure 3 can be substantially the same as the power supply 140, the load 142, and the battery system 102 of Figures 1A and 1B, except as described below.

[0095] In this case, the battery system 302 includes a distribution unit 345 and at least one battery module 390 that are detachably coupled to each other. The distribution unit 345 can include at least one DC/DC converter 349 and a number of switches 370. The distribution unit 345 can be an assembly of components within, on, and/or proximate to a housing. Alternatively, the distribution unit 345 can be an assembly of components without a housing. The distribution unit 345 can include one or more of a number of coupling features (e.g., electrical connector ends) that allow the distribution unit 345 to be coupled to the power supply 340 and the load 342.

[0096] The distribution unit 345 can also include one or more of a number of coupling features that allow the distribution unit 345 to detachably couple to each of the battery modules 390. Examples of such coupling features are discussed more fully below with respect to Figures 9A-10B. The distribution unit 345 is coupled to the power supply 340, the load 342, and each of the battery modules 390 using one or more signal transfer links 305 and/or one or more power transfer links 385.

[0097] Each battery module 390 can include one or more of a number of components. For example, as shown in Figure 3, a battery module 390 can include a controller 304, one or more temperature control devices 372, one or more pressure regulating devices 374, one or more sensors 360, one or more switches 370, one or more battery cells 395 (e.g., battery cell 395-1, battery cell 395-N), and a safety device 319. The controller 304, each control device 372, each pressure regulating device 374, each sensor 360, and each switch 370 (or any portions thereof) can be substantially the same as the corresponding components described above with respect to Figures 1A and 1B. A

battery cell 395 can use one or more of any number of storage technologies. Examples of such technologies can include, but are not limited to, nickel-cadmium, nickel-metalhydride, lithium-ion, lithium polymer, lithium iron phosphate, and alkaline.

[0098] The safety device 319 of the battery module 390 can be used to ensure that the electrical connection (a form of coupling device) between the battery module 390 and the distribution unit 345 is not exposed and/or has no power flowing to it when the battery module 390 and the distribution unit 345 are decoupled from each other. Since the stored power released by the battery cells 395 (and so also the battery module 390) is typically DC power, the risk of electrical shock, ground faults, and/or other adverse conditions are great when the leads (e.g., connector pins, electrical conductors) of the battery module 390 are exposed. The safety device 319 is designed to prevent these adverse conditions.

[0099] In certain example embodiments, the safety device 319 can work (e.g., become engaged, become disengaged) in conjunction with one or more sensors 360 (e.g., a Hall Effect sensor, a proximity sensor). In addition, or in the alternative, the safety device 319 can work in conjunction with a locking bar, as described below. The distribution unit 345 can also have one or more safety devices 319 in certain example embodiments to cover, retract, and/or otherwise disable a coupling feature that includes an electrical connection. For example, a safety device 319 can mechanically cover a coupling feature of the distribution unit 345 when a corresponding battery module 390 is decoupled and removed from the system 300. In such a case, the coupling feature can be protected from salt water, dirt, and/or other contaminants that can cause corrosion, a fault, and/or any other adverse condition.

[00100] Figure 4 shows a subassembly 481 that includes a battery system 402 in accordance with certain example embodiments. Referring to Figures 1A-4, the subassembly 481 can include any one or more of a number of components serving any of a number of purposes. In this case, the subassembly 481 is a mudline closure device (MCD) that replaces at least part of a blow-out preventer (BOP) used for a subsea field operation. The subassembly 481 has a frame 483 that is used to assemble the various components of the subassembly 481. The frame 483 can have one or more walls to enclose a space therein. Alternatively, the frame 483 can be open.

[00101] In this case, the subassembly 481 includes a number (e.g., six) battery assemblies 482, where each battery assembly 482 includes a battery system 402. A battery assembly 482 of the subassembly 481 can be configured (e.g., number of battery

modules, size of battery modules, overall size, types of sensors) substantially the same as, or differently than, the other battery assemblies 482 of the subassembly 481.

[00102] Figures 5A-5C show various views of a battery assembly 582 that includes a battery system 502 in accordance with certain example embodiments. The battery assembly 582 of Figures 5A-5C can be substantially the same as the battery assembly 482 of Figure 4. Referring to Figures 1A-5C, the battery subassembly 582 of Figures 5A-5C includes a battery system 502 and a load 542. The battery subassembly 582 can also include a power supply (not shown). Alternatively, the power supply can be located outside of the battery subassembly 582, in which case the battery system 502 can be coupled to the power supply using one or more signal transfer links 505 and/or one or more power transfer links 585.

[00103] The battery subassembly 582 can have a frame 587, similar to the frame 483 of the subassembly 481, that is used to assemble the various components of the battery subassembly 582. The frame 587 can have one or more walls to enclose a space therein. Alternatively, the frame 587 can be open. Here, there is a floor 584 on which the battery modules 590 are disposed, as well as a floor 586 on which the load 542 is disposed.

[00104] The battery system 520 in this case includes six battery modules 590 (battery module 590-1, battery module 590-2, battery module 590-3, battery module 590-4, battery module 590-5, and battery module 590-6). These battery modules 590 are aligned side by side in a single row. The battery system 502 in this example also includes a locking bar 560, described below, that are used to secure the battery modules 590 relative to the busbar (hidden from view in Figures 5A-5C).

[00105] Figures 6A and 6B show various views of another battery assembly 689 in accordance with certain example embodiments. Referring to Figures 1A-6B, the battery assembly 689 of Figures 6A and 6B is substantially the same as the battery assembly 582 of Figures 5A-5C, except that only the frame 687 and the battery system 602 remain, and all other components (e.g., the floor 586, the load 542, the signal transfer links 505, the power transfer links 585) from the battery assembly 582 have been removed. In this way, the busbar 645 of the battery system 602 can be viewed.

[00106] Figures 7A-7F show various views of a battery module 790 in accordance with certain example embodiments. Specifically, Figure 7A shows a front-top-side perspective view of the battery module 790. Figure 7B shows a rear-top-side perspective

view of a portion of the battery module 790. Figure 7C shows a front-top-side semi-exploded perspective view of a portion of the battery module 790. Figure 7D shows a front-bottom-side perspective view of a battery pack 735 of the battery module 790. Figure 7E shows a front-bottom-side perspective view of a portion of the battery pack 735 of the battery module 790. Figure 7F shows a front-bottom-side perspective view of a battery cell 775 of the battery module 790.

[00107] Referring to Figures 1A-7F, the battery module 790 can be substantially the same as the battery modules described above, except as described below. A battery module 790 can include a housing 703. The housing 703 can include one or more walls. For example, in this case, the housing 703 includes a top wall 792, a front wall 793, a rear wall 795, a left side wall 796, a right side wall 794, and a bottom wall (hidden from view). The housing 703 can have one or more of a number of user features 791 disposed on one or more of its walls. A user feature 791 can be used by a user (e.g., user 150) to insert, remove, and/or otherwise handle the battery module 790. For example, in this case, the user feature 791 is a handle disposed on the front wall 793 of the housing 703. Examples of other user features 791 can include, but are not limited to, a recess, a detent, a slot, a tab, and a protrusion.

[00108] Further, the housing 703 can have one or more of a number of coupling features disposed on one or more of its walls. Such coupling features can be used for electrical and/or mechanical coupling with another component (e.g., the busbar) of the battery system. For example, as shown in Figures 7A-7C, the housing 703 can include coupling feature 751 (which in this case is a female electrical receptacle for power signals), coupling feature 752 (which in this case is a female electrical receptacle for control and communication signals), and a pair of coupling features 753 (which in this case are pins having a pin body 754 and a notch 755 disposed along part of the top of the pin body 754). As described below, these coupling features are configured to complement one or more other components (e.g., the busbar, the locking bar) of the battery system.

[00109] Further, in conjunction with a safety feature (e.g., safety device 319 of Figure 3 above), the housing 703 can include one or more indicating devices to indicate the status of some aspect of the battery module 790. While not shown in this case, examples of such an indicating device can include, but are not limited to, an indicating light (e.g., having a color indicating a status), a flag (e.g., having a color indicating a status), and a sign (e.g., having wording indicating a status).

[00110] The housing 703 can at least partially enclose one or more battery packs 735. When there are multiple battery packs 735 in a battery module 790, one of the battery packs 735 can be arranged (electrically coupled) in series and/or in parallel with the other battery packs 735 in the battery module 790. In this case, there are six battery packs 735 (battery pack 735-1, battery pack 735-2, battery pack 735-3, battery pack 735-4, battery pack 735-5, and battery pack 735-6) that are aligned in series with each other. Adjacent battery packs 735 can be electrically coupled to each other in one or more of a number of ways. For example, while hidden from view in this case, adjacent battery packs 735 can be electrically coupled to each other using laser-welded connections. As another example, adjacent battery packs 735 can be electrically coupled to each other using complementary mechanical connector ends.

[00111] To assist with the alignment of the battery packs 735 within the housing 703, the housing 703 and/or the battery packs 735 can include one or more of a number of features. For example, in this case, the housing 703 includes a number (in this case, four) pins 731 that extend from the front wall 793 to the back wall 795. These pins 731 can align with and be disposed within apertures 737 that traverse the thickness (e.g., measured by a side wall 738) of each battery pack 735.

[00112] Each battery pack 735 can have a lid 736 that can be removed to expose one or more battery cells 775. When there are multiple (e.g., 12) battery cells 775 in a battery pack 735, one of the battery cells 775 can be arranged (electrically coupled) in series and/or in parallel with the other battery cells 775 in the battery pack 735. In this case, there are multiple battery cells 775 that are aligned in series with each other. Adjacent battery cells 775 can be electrically coupled to each other in one or more of a number of ways. For example, while hidden from view in this case, adjacent battery cells 775 can be electrically coupled to each other using laser-welded connections along the one or more terminal extensions 777 that extend from the top wall of the battery cell 775. As another example, adjacent battery cells 775 can be electrically coupled to each other using complementary mechanical connector ends.

[00113] Each battery cell 775 can have any of a number of configurations. For example, as shown in this case, the battery cell 775 is substantially rectangular when viewed at the front surface 776, and the thickness of the battery cell 775 (measured as the height of the side wall 778) can be small relative to the length and width of the front surface 776. While the terminal extensions 777 can extend from the top wall, such

terminal extensions 777 can extend from any other wall and/or surface of the battery cell 775. When there are multiple battery cells 775 in a battery pack 735, one battery cell 775 can have the same and/or different characteristics (e.g., capacity, size, shape) as one or more of the other battery cells 775.

[00114] Figure 8 shows a locking bar 860 in accordance with certain example embodiments. Referring to Figures 1A-8, the locking bar 860 shows an example of how one or more of the battery modules can be mechanically secured relative to the busbar for an example battery system. In this case, the locking bar 860 has a body 862 that has a number (e.g., one, three, six) of notches 863 disposed along part of a side of the body 862. The locking bar 860 can also include a handle 861 disposed on an end (e.g., a proximal end, a distal end) of the body 862.

[00115] The notches 863 can have a shape, size, location, and/or other characteristics that complement one or more characteristics (e.g., notch 755) of a coupling feature (e.g., coupling feature 753) of another component (e.g., battery module 790) of the example battery system. The body 862 of the locking bar 860 can have any of a number of cross-sectional shapes and/or sizes when viewed along the length of the body 862. Such shapes can include, but are not limited to, a circle (as in this case), an oval, a square, an ellipse, and an octagon. Figures 9A-10B below show how an example locking bar (e.g., locking bar 860) can be used in a battery system.

[00116] Figures 9A-10B show various views of a subassembly that includes a battery system in accordance with certain example embodiments. Specifically, Figure 9A shows a top-side perspective view of a portion of the subassembly 988 with a battery module 990 decoupled from the busbar 945 of the battery system 902. Figure 9B shows a side view of the subassembly 988 with the battery module 990 decoupled from the busbar 945 of the battery system 902. Figure 9C shows a cross-sectional side view of the subassembly 988 with the battery module 990 decoupled from the busbar 945 of the battery system 902. Figure 10A shows a side view of a subassembly 1088 with the battery module 990 coupled to the busbar 945 of the battery system 902. Figure 10B shows a cross-sectional side view of the subassembly 1088 with the battery module 990 coupled to the busbar 945 of the battery system 902.

[00117] Referring to Figures 1A-10B, when the battery module 990 is decoupled from the busbar 945, the position of the locking bar 960 can be manipulated to allow the battery module 990 to become coupled to the busbar 945 and/or to prevent the battery

module 990 from becoming coupled to the busbar 945. In this case, the position of the locking bar 960 can be adjusted by rotating the handle 961, which in turn rotates the body 962 (and associated notches 963) to a certain position about an axis defined by the length of the body 962.

[00118] The locking bar 960 can be held in place, at least in part, by one or more guides 965 affixed to (or part of) the frame 987 or some other portion of the subassembly 988. Each guide 965 can have one or more features that prevent certain movements of the locking bar 960 while allowing other movements of the locking bar 960. Examples of such features 964 can include, but are not limited to, an aperture, a slot, a detent, a latch, a stop, a recess, a protrusion, and a tab. In this case, the feature 964 is an aperture that traverses the thickness of the guide 965. The aperture 964 in this example allows for rotation of the locking bar 960 about an axis defined by the length of the body 962, while preventing movement of the locking bar along the axis defined by the length of the body 962. In this way, the notches 963 in the body 962 of the locking bar 960 can be linearly aligned with the notches 955 in each coupling feature 953 of each battery module 990.

[00119] When the locking bar 960 is in a certain position (e.g., an unlocked position) where the notches 963 are facing along the bottom of the body 962, adjacent to the passage of the body 954 of the coupling features 953 of each battery module 990, the body 954 of the coupling features 953 of each battery module 990 can slide in one direction (e.g., toward the busbar 945) or an opposite direction (e.g., away from the busbar 945).

[00120] As described above, the busbar 945 can include one or more of a number of coupling features that complement the coupling features of the battery module 990. In this example, the coupling features of the battery module 990 of Figures 9A-10B are substantially the same as the coupling features of the battery module 990 of Figures 7A-7C. As a result, the busbar 945 has a set of coupling features for each battery module 990. As shown in Figures 9A-9C, each set of coupling features of the busbar 945 can include coupling feature 943 (which in this case is a male electrical receptacle for power signals), coupling feature 941 (which in this case is a male electrical receptacle for control and communication signals), and a pair of coupling features 947 (which in this case are apertures or pin receivers disposed in the busbar 945).

[00121] When a battery module 990 is placed within the frame 987 of the subassembly 988, the coupling features of the battery module 990 align with one of the

sets of coupling features of the busbar 945. Specifically, coupling feature 951 of the battery module 990 aligns with one of coupling feature 943 (e.g., coupling feature 943-1, coupling feature 943-2) of the busbar 945; coupling feature 952 of the battery module 990 aligns with one of coupling feature 941 (e.g., coupling feature 941-1, coupling feature 941-2) of the busbar 945; and the pair of coupling features 953 of the battery module 990 aligns with the pair of coupling features 947 (e.g., coupling feature 947-1, coupling feature 947-2) of the busbar 945.

[00122] As stated above, when the locking bar 960 is rotated or otherwise placed in the open position, one or more of the battery modules 990 can be pushed toward the busbar 945 until the various coupling features (in this case, coupling feature 951, coupling feature 952, and coupling features 953) couple to their corresponding coupling features (in this case, coupling feature 943, coupling feature 941, and coupling features 947) of the busbar 945. Once the battery module 990 is coupled to the busbar 945, the locking bar 960 can be rotated or otherwise moved into the closed position, as shown in Figures 10A and 10B.

[00123] In this example, but rotating the locking bar 960 by approximately 180° (or even some lesser or greater amount), the notches 963 in the locking bar avoid (are no longer adjacent to) the body 954 of the coupling features 953 of the battery module 990, and the body 962 of the locking bar 960 is disposed within the notches 955 of the coupling features 953 of the battery module 990. By maintaining this position (the closed or locked position) of the locking bar 960 relative to the coupling features 953 of the battery module 990, the battery module 990 cannot be removed from the subassembly 1088, which means that the battery module 990 remains coupled to the busbar 945. Also, as shown in 10A, the user feature 991 does not extend beyond the frame 987 of the subassembly 1088 when the associated battery module 990 is coupled to the busbar 945.

[00124] As stated above, the locking bar 960 is only one of a number of ways of ensuring that one or more battery modules 990 remain coupled to the busbar 945. In addition, there can be more than one locking bar 960 (or similar device or mechanism) associated with a single battery system 902. When there are multiple locking bars 960 (or similar devices or mechanisms) associated with a single battery system 902, than a single locking bar 960 can control the movement of one or multiple battery modules 990 relative to the busbar 945. The position of the locking bar 960 can be controlled manually (as by a user 150), automatically (as by a controller 104), and/or by any other suitable means.

[00125] The systems, methods, and apparatuses described herein allow for the use of smaller, simpler, more reliable, and more effective systems that require power in subsea and marine environments. Further, because of the modular design of the example systems described herein, a battery module can be removed and/or replaced at any time in a safe manner and can be done without interrupting electrical service to the connected load. In some cases, the example battery modules can be designed to provide high levels of stored power to the load, which can at times require such high levels of power.

[00126] In some cases, legislation may require that the weight of certain battery cells (e.g., lithium ion cells) in a battery pack are limited for air or other types of transport. By splitting the battery system into smaller example battery modules, example embodiments can be shipped in accordance with existing and future regulations and requirements. Further, by including the example busbar, the battery modules can be connected subsea in a safe and highly reliable fashion. In the event that there is a problem with one battery module, it can be swapped out and replaced safely and without disruption to the load.

[00127] Further, multiple battery systems can be used simultaneously to serve a load. In such a case, an entire battery system can be replaced without disrupting service to the load. In any case, by using example embodiments, the failure of a battery system, a battery module, a battery pack, or a battery cell does not affect the provision of stored power to the load being served.

[00128] By regulating the temperature of the battery system (or portions thereof) while in service in a subsea environment, which is often very cold, the useful life and level of service of the battery modules in example embodiments can be increased. Similarly, by regulating the pressure of the battery system (or portions thereof) while in service in a subsea environment, the useful life and level of service of the battery modules in example embodiments can be increased.

[00129] A controller included with example embodiments can track the performance of various aspects of a battery system. In such a case, the controller can perform a number of functions to improve the reliability and performance of the example battery system, including but not limited to forecasting when a component of an example battery system may fail, implementing procedures and protocols to optimize the performance of the battery system, and notifying a user when a failure of a component of the battery system has occurred.

[00130] Although embodiments described herein are made with reference to example embodiments, it should be appreciated by those skilled in the art that various modifications are well within the scope and spirit of this disclosure. Those skilled in the art will appreciate that the example embodiments described herein are not limited to any specifically discussed application and that the embodiments described herein are illustrative and not restrictive. From the description of the example embodiments, equivalents of the elements shown therein will suggest themselves to those skilled in the art, and ways of constructing other embodiments using the present disclosure will suggest themselves to practitioners of the art. Therefore, the scope of the example embodiments is not limited herein.

CLAIMS

What is claimed is:

1. A battery system for use in a subsea field operation, comprising:

a plurality of first battery modules, wherein each first battery module of the plurality of first battery modules comprises a housing and a first coupling feature disposed on the housing, wherein the housing is rated for subsea conditions; and

a first busbar comprising a plurality of second coupling features, wherein the first coupling feature of each first battery module is removably coupled to a second coupling feature of the plurality of second coupling features of the first busbar,

wherein the first busbar is electrically coupled to each first battery module when the first coupling feature is coupled to the second coupling feature, wherein each first battery module delivers stored power to the first busbar through the first coupling feature and the second coupling feature.

2. The battery system of Claim 1, wherein each first battery module comprises a plurality of battery packs disposed within the housing, wherein each battery pack of the plurality of battery packs comprises a plurality of battery cells.

3. The battery system of Claim 1, wherein each first battery module of the plurality of first battery modules further comprises a third coupling feature disposed on the housing, wherein the busbar further comprises a plurality of fourth coupling features, wherein the third coupling feature couples to a fourth coupling feature of the plurality of fourth coupling features when the first coupling feature couples to the second coupling feature.

4. The battery system of Claim 3, wherein the third coupling feature and the fourth coupling feature, when coupled to each other, transfer communication signals between the first busbar and the first battery module.

5. The battery system of Claim 3, wherein each first battery module of the plurality of first battery modules further comprises a fifth coupling feature, wherein the

busbar further comprises a plurality of sixth coupling features, wherein the fifth coupling feature couples to a sixth coupling feature of the plurality of sixth coupling features when the first coupling feature couples to the second coupling feature.

6. The battery system of Claim 5, further comprising:

a first locking bar disposed between the first busbar and the plurality of first battery modules proximate to the plurality of sixth coupling features, wherein the first locking bar has a first position and a second position.

7. The battery system of Claim 6, wherein the fifth coupling feature protrudes from the housing of the first battery module, wherein the fifth coupling feature comprises a receiving feature, wherein the first locking bar, when in the first position, is disposed within the receiving feature and prevents the first coupling feature from becoming decoupled from the second coupling feature, and wherein the first locking bar, when in the second position, is disposed outside the receiving feature and allows the first coupling feature to become decoupled from the second coupling feature.

8. The battery system of Claim 6, wherein the sixth coupling feature protrudes from the first busbar, wherein the sixth coupling feature comprises a receiving feature, wherein the first locking bar, when in the first position, is disposed within the receiving feature and prevents the first coupling feature from becoming decoupled from the second coupling feature, and wherein the first locking bar, when in the second position, is disposed outside the receiving feature and allows the first coupling feature to become decoupled from the second coupling feature.

9. The battery system of Claim 6, wherein each first battery module of the plurality of first battery modules further comprises a seventh coupling feature, wherein the busbar further comprises a plurality of eighth coupling features, wherein the seventh coupling feature couples to an eighth coupling feature of the plurality of eighth coupling features when the first coupling feature couples to the second coupling feature.

10. The battery system of Claim 9, wherein the seventh coupling feature protrudes from the housing of the first battery module, wherein the seventh coupling

feature comprises the receiving feature, wherein the first locking bar, when in the first position, is disposed within the receiving feature, and wherein the first locking bar, when in the second position, is disposed outside the receiving feature.

11. The battery system of Claim 1, further comprising:

a controller that controls when the stored power is delivered from the plurality of first battery modules to the busbar.

12. The battery system of Claim 11, further comprising:

at least one switch that is operated by the controller, wherein the at least one switch has a first position and a second position, wherein the first position allows the stored power to flow to the busbar, and wherein the second position prevents the stored power from flowing to the busbar.

13. The battery system of Claim 1, wherein one of the plurality of first battery modules is connected in parallel with respect to a remainder of the plurality of first battery modules.

14. The battery system of Claim 13, wherein the remainder of the plurality of first battery modules continue to deliver the stored power to the busbar when the one of the plurality of first battery modules is decoupled from the busbar.

15. The battery system of Claim 1, further comprising:

a plurality of second battery modules, wherein each second battery module of the plurality of second battery modules comprises the housing and the first coupling feature disposed on the housing; and

a second busbar comprising the plurality of second coupling features, wherein the first coupling feature of each second battery module is removably coupled to the second coupling feature of the plurality of second coupling features of the second busbar,

wherein the second busbar is electrically coupled to each second battery module when the first coupling feature is coupled to the second coupling feature, wherein each second battery module delivers the stored power to the second busbar through the first coupling feature and the second coupling feature, and

wherein the second busbar is electrically coupled to the first busbar.

16. The battery system of Claim 1, further comprising:

a temperature regulation module comprising at least one sensor, wherein the at least one sensor measures a temperature within the housing, and wherein the temperature regulation module adjusts the temperature.

17. The battery system of Claim 1, further comprising:

a pressure regulation module comprising at least one sensor, wherein the at least one sensor measures a pressure within the housing, and wherein the pressure regulation module adjusts the pressure within the housing.

18. The battery system of Claim 1, wherein each first battery module of the plurality of first battery modules further comprises an isolation module, wherein the isolation module isolates the first coupling feature from a battery pack grouping within the housing when the first coupling feature is decoupled from the second coupling feature of the busbar.

19. The battery system of Claim 18, wherein each first battery module of the plurality of first battery modules further comprises an indicating device, wherein the indicating device provides confirmation to a user that the first coupling feature is isolated from the battery pack grouping within the housing.

20. A mudline closure device for use in a subsea field operation, comprising:

a power supply;

a load used for disconnecting wellbore equipment from surface equipment; and

a battery system coupled to the power supply and the load, wherein the battery system comprises:

a plurality of battery modules, wherein each battery module of the plurality of battery modules comprises a housing and a first coupling feature disposed on the housing, wherein the housing is rated for subsea conditions; and

a busbar comprising a plurality of second coupling features, wherein the first coupling feature of each battery module is removably coupled to a second coupling feature of the plurality of second coupling features of the busbar,

wherein the busbar is electrically coupled to each battery module when the first coupling feature is coupled to the second coupling feature, and wherein each battery module delivers stored power to the load through the first coupling feature, the second coupling feature, and the busbar.

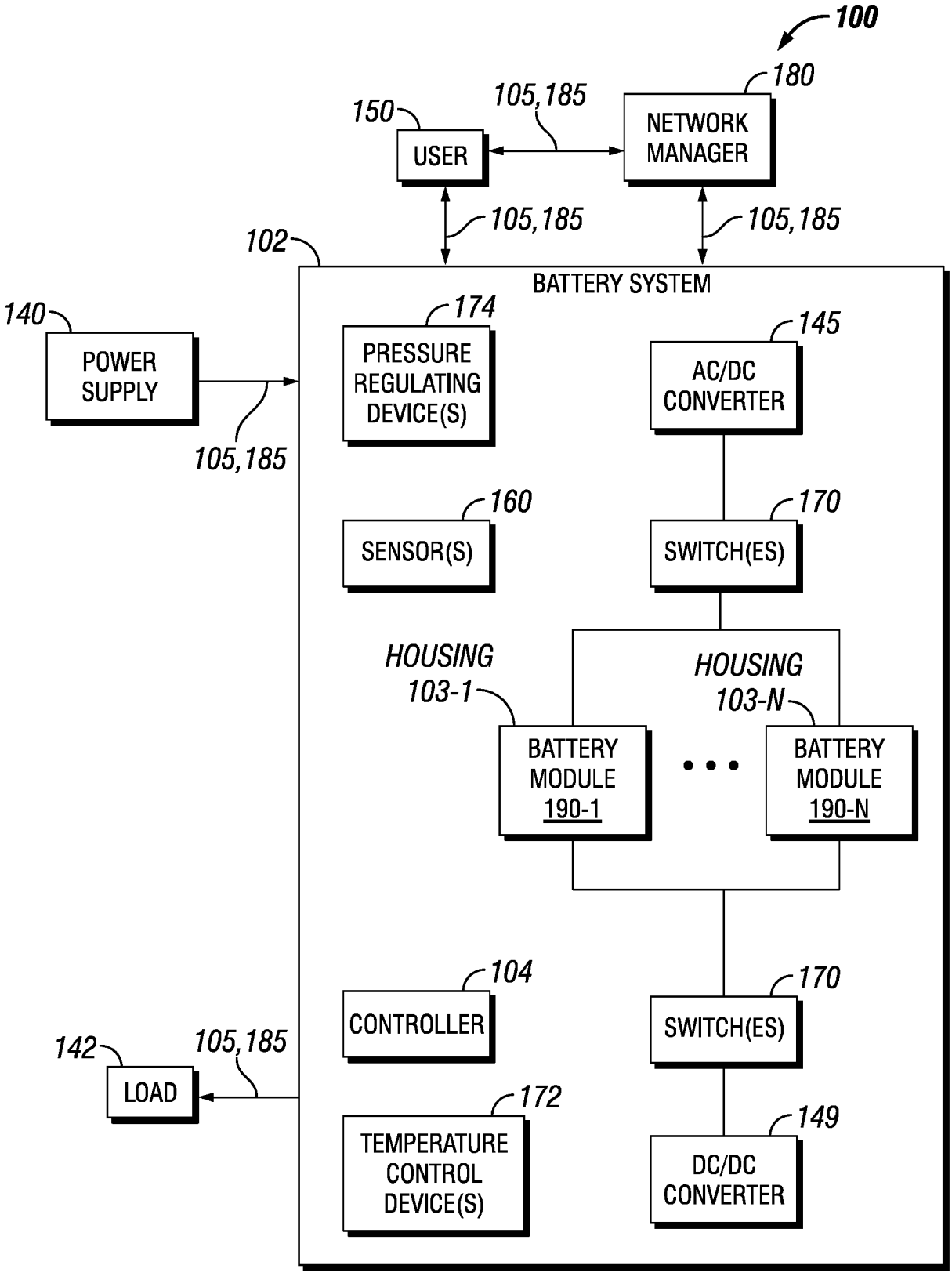

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180
NETWORK MANAGER
105,185
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USER
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105,185
102
BATTERY SYSTEM
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POWER SUPPLY
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174
PRESSURE REGULATING DEVICE(S)
145
AC/DC CONVERTER
160
SENSOR(S)
170
SWITCH(ES)
HOUSING 103-1
HOUSING 103-N
BATTERY MODULE 190-1
BATTERY MODULE 190-N
104
CONTROLLER
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SWITCH(ES)
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LOAD
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TEMPERATURE CONTROL DEVICE(S)
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DC/DC CONVERTER

FIG. 1A

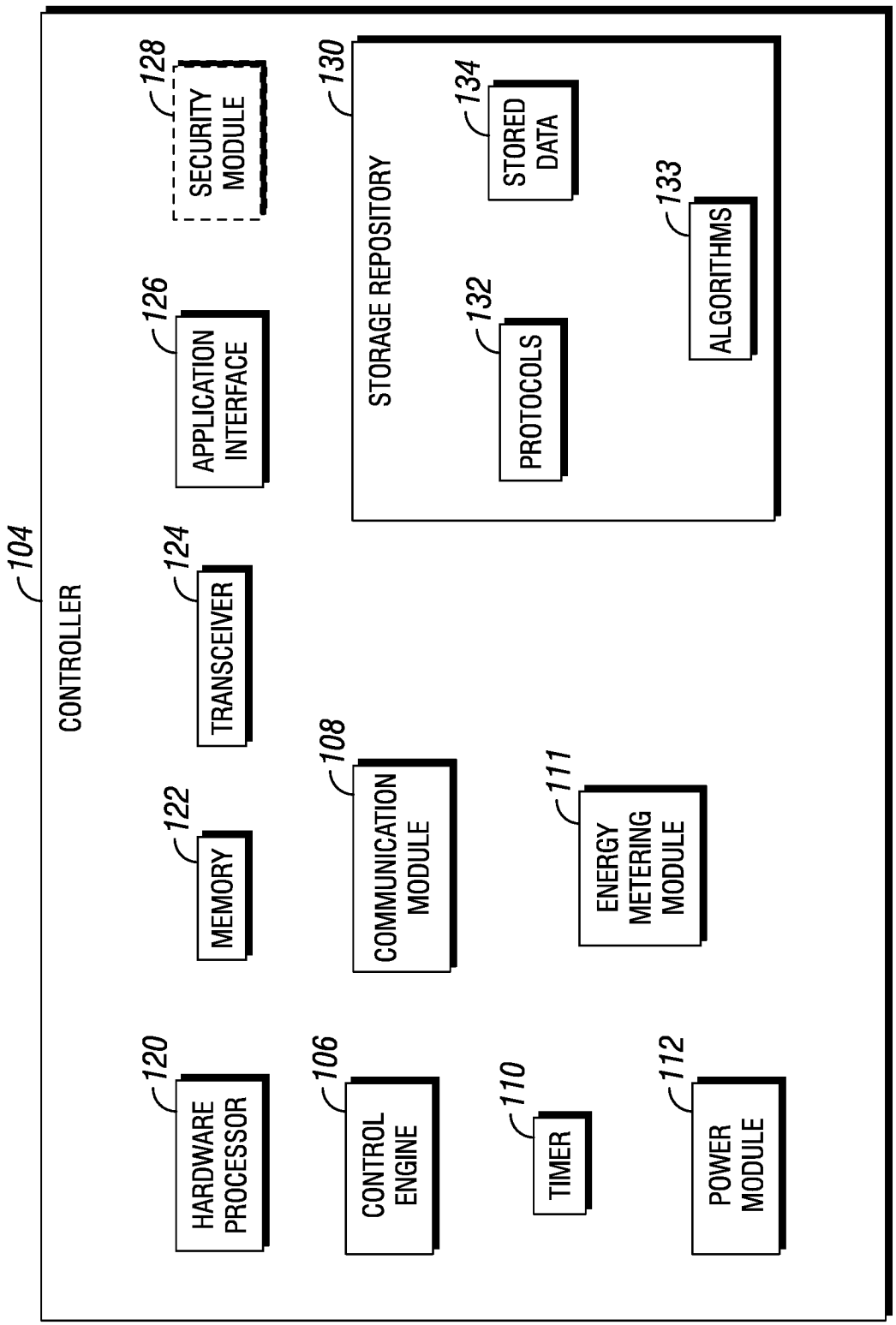

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CONTROLLER
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HARDWARE PROCESSOR
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CONTROL ENGINE
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TIMER
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POWER MODULE
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MEMORY
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COMMUNICATION MODULE
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ENERGY METERING MODULE
124
TRANSCEIVER
126
APPLICATION INTERFACE
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PROTOCOLS
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ALGORITHMS
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STORED DATA

FIG. 1B

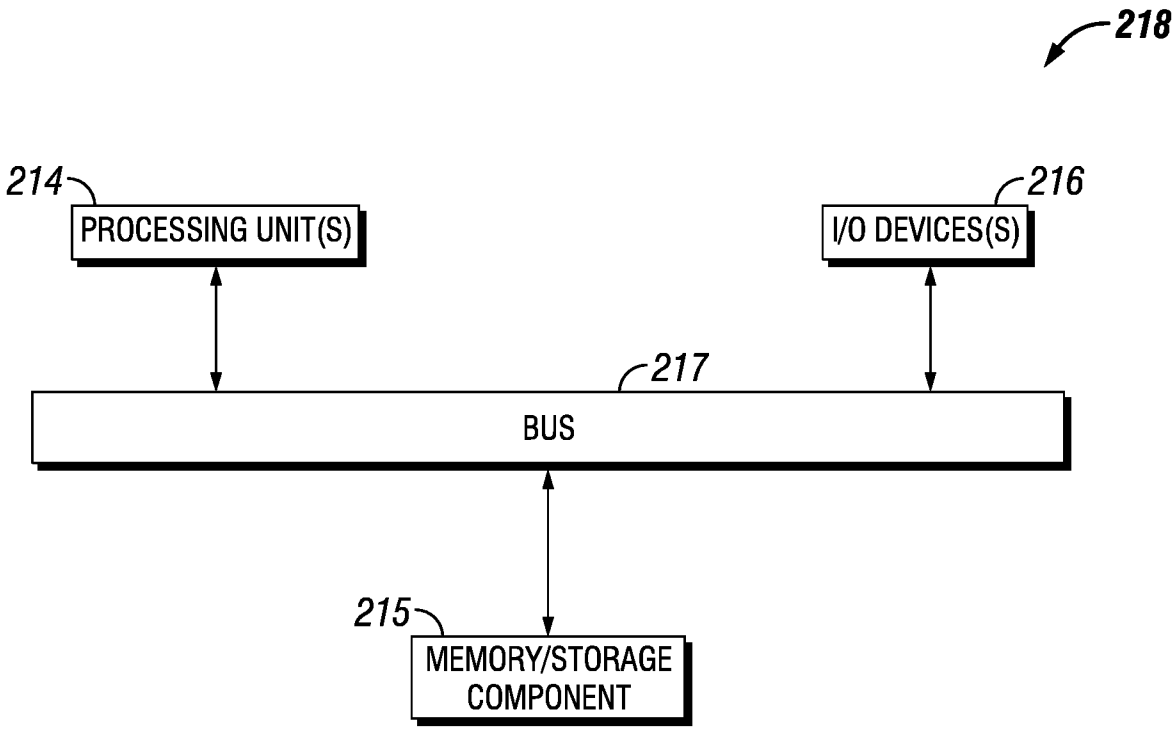

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PROCESSING UNIT(S)
216
I/O DEVICES(S)
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BUS
215
MEMORY/STORAGE
COMPONENT

FIG. 2

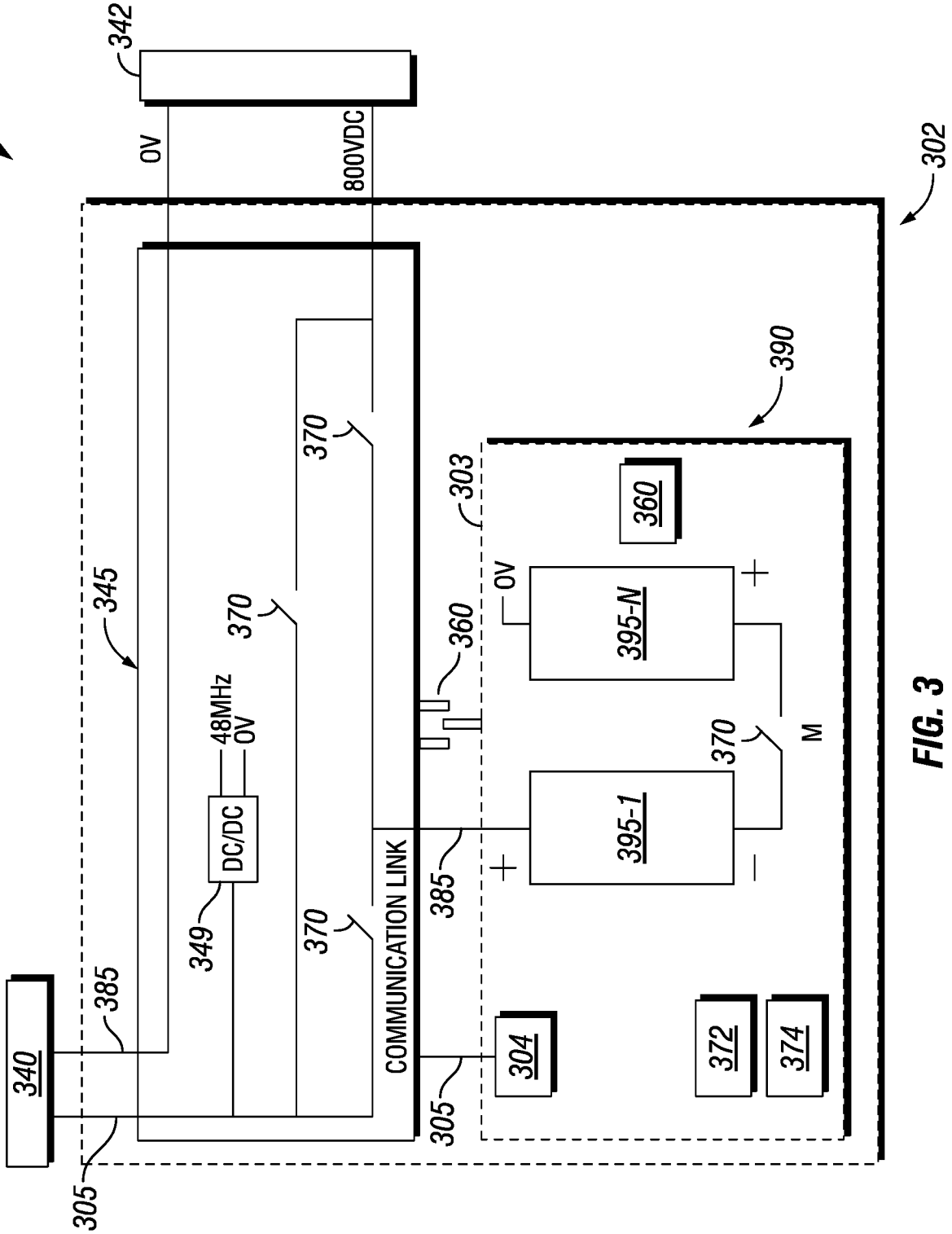

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FIG. 3

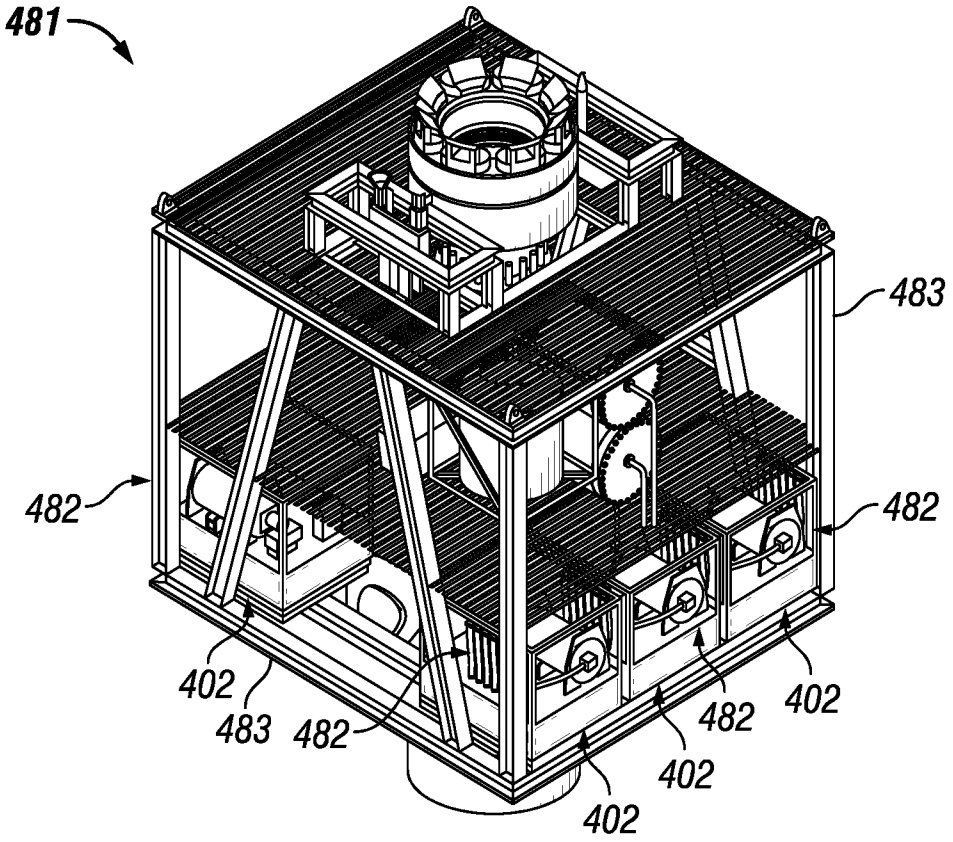

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FIG. 4

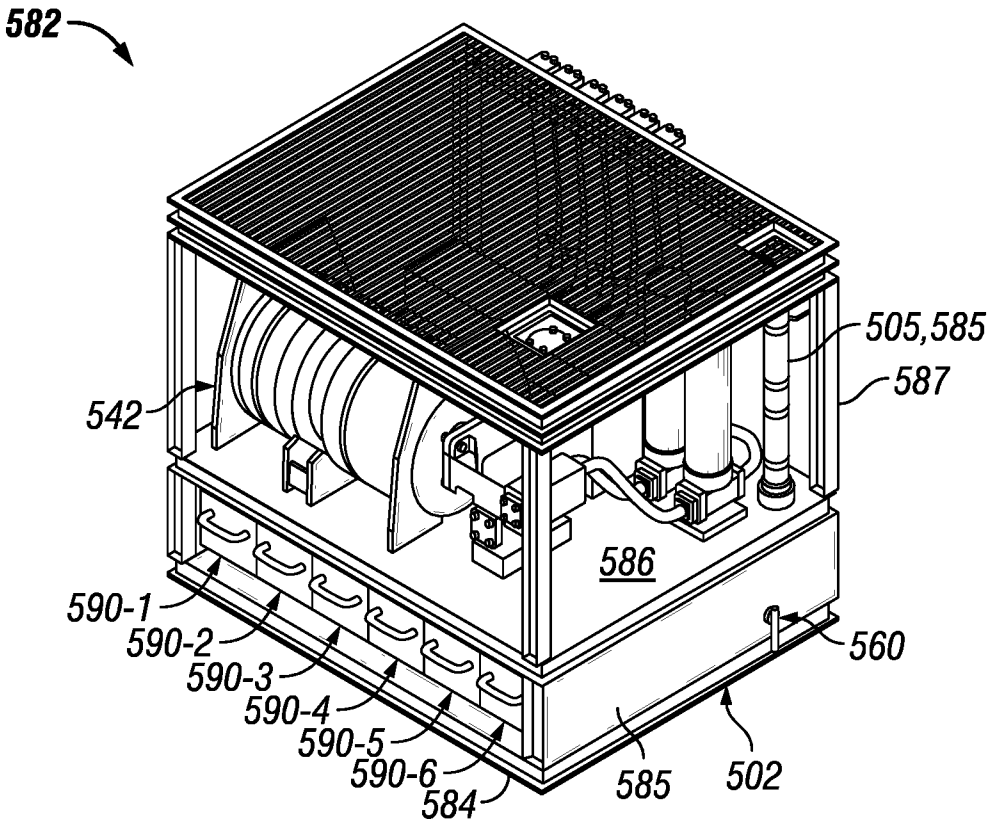

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FIG. 5A

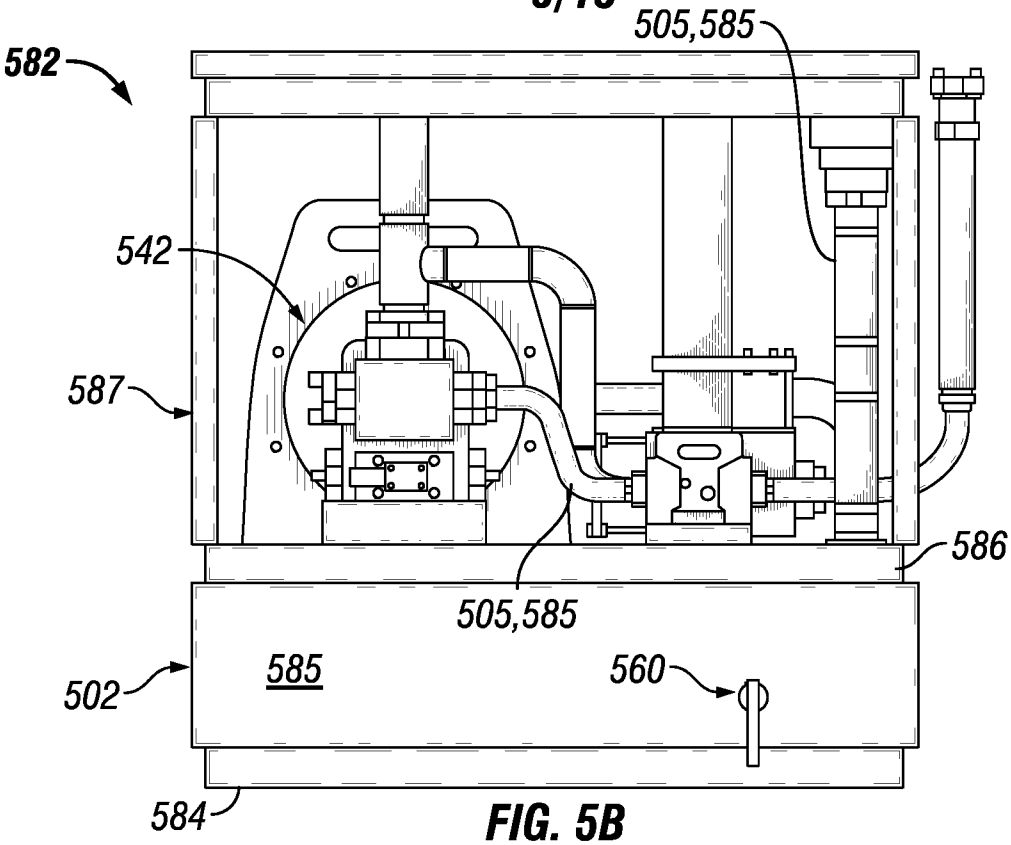

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FIG. 5B

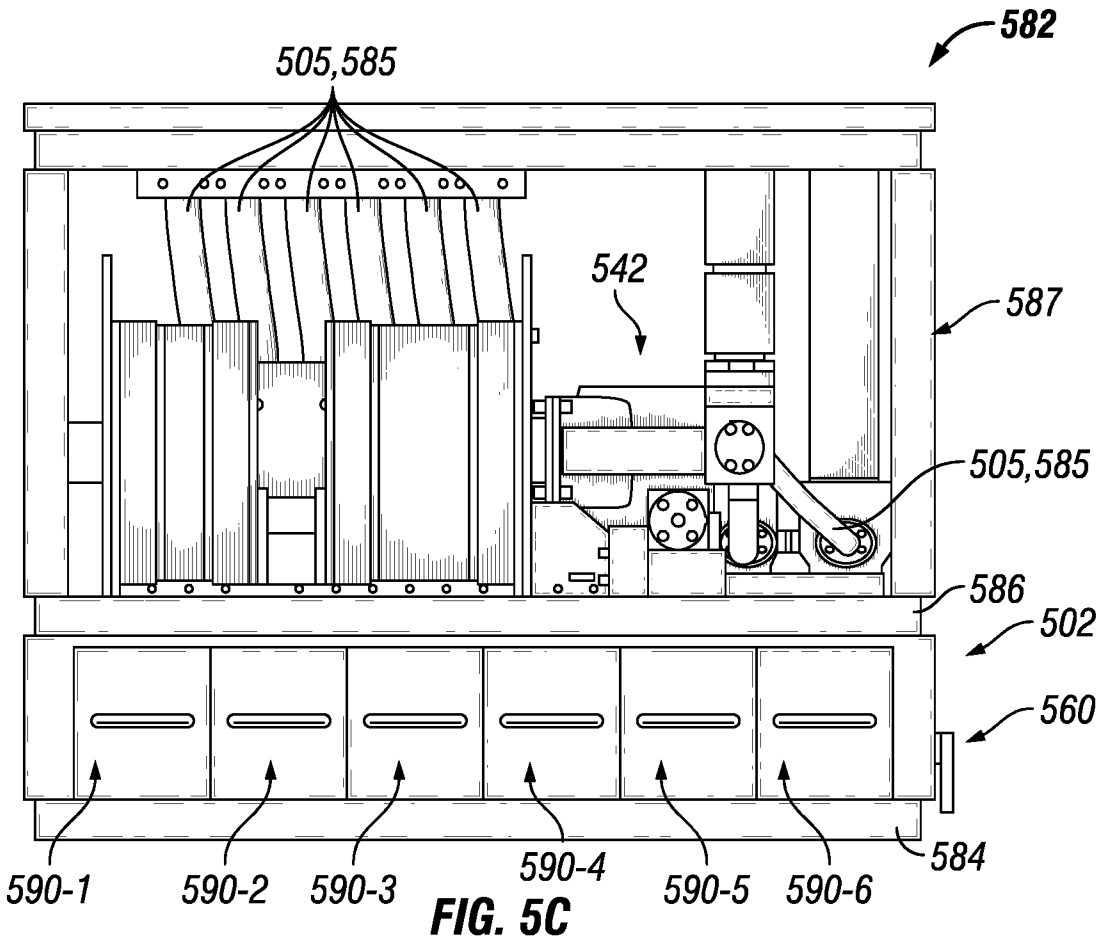

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FIG. 5C

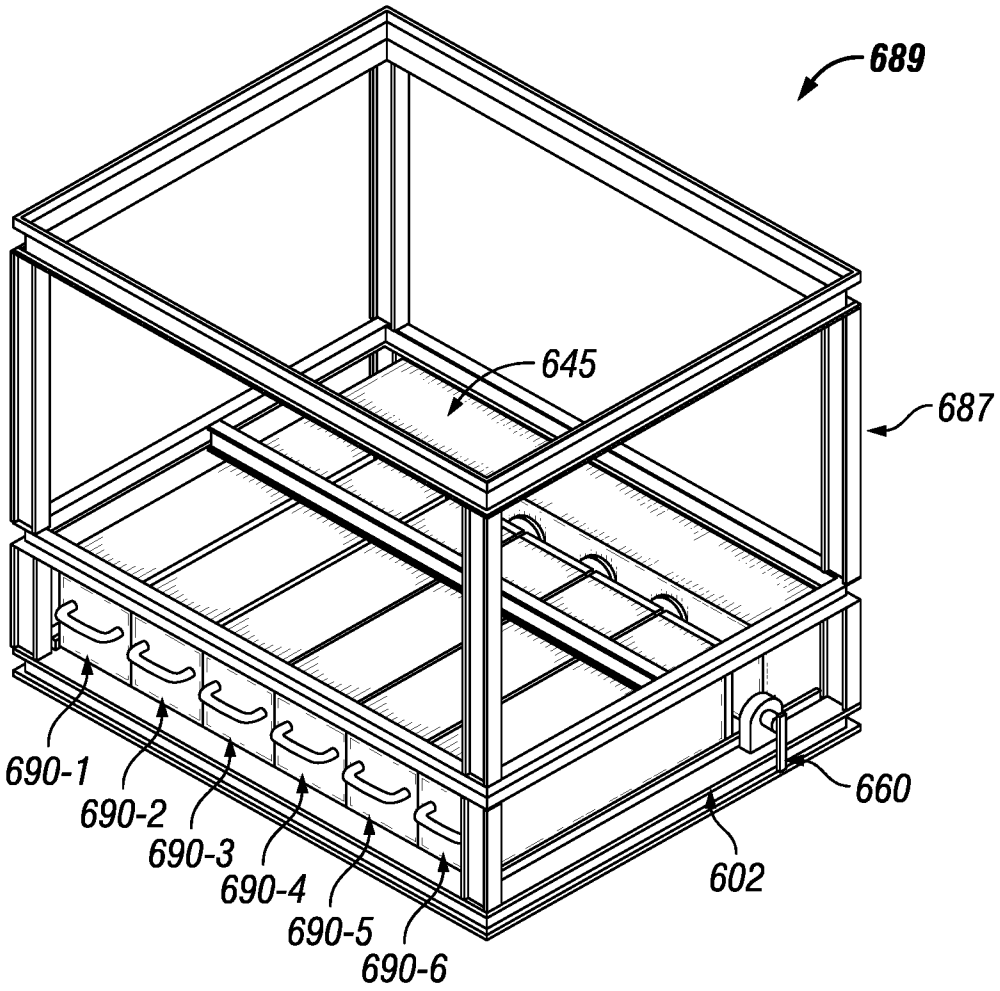

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FIG. 6A

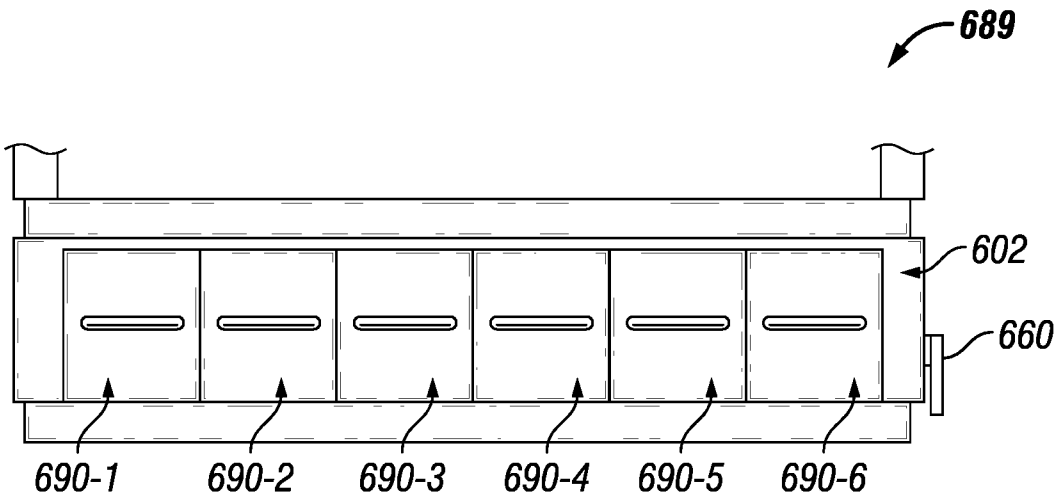

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FIG. 6B

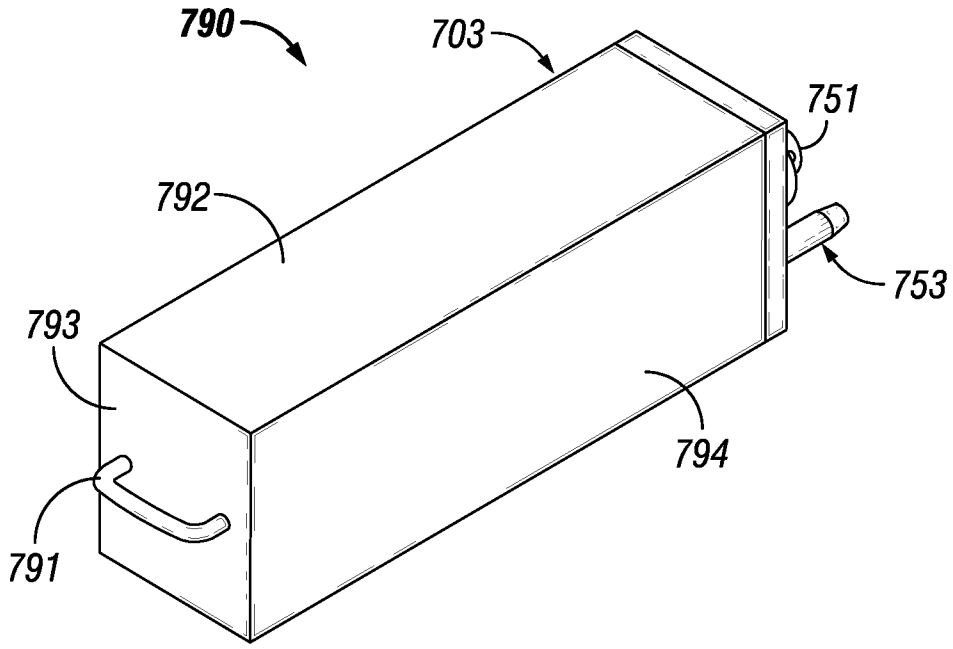

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FIG. 7A

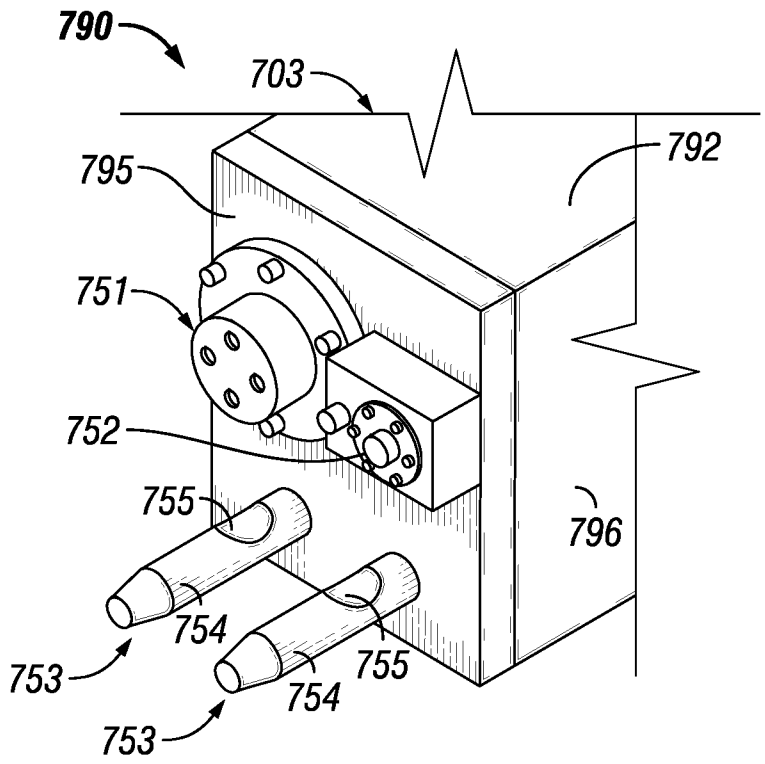

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FIG. 7B

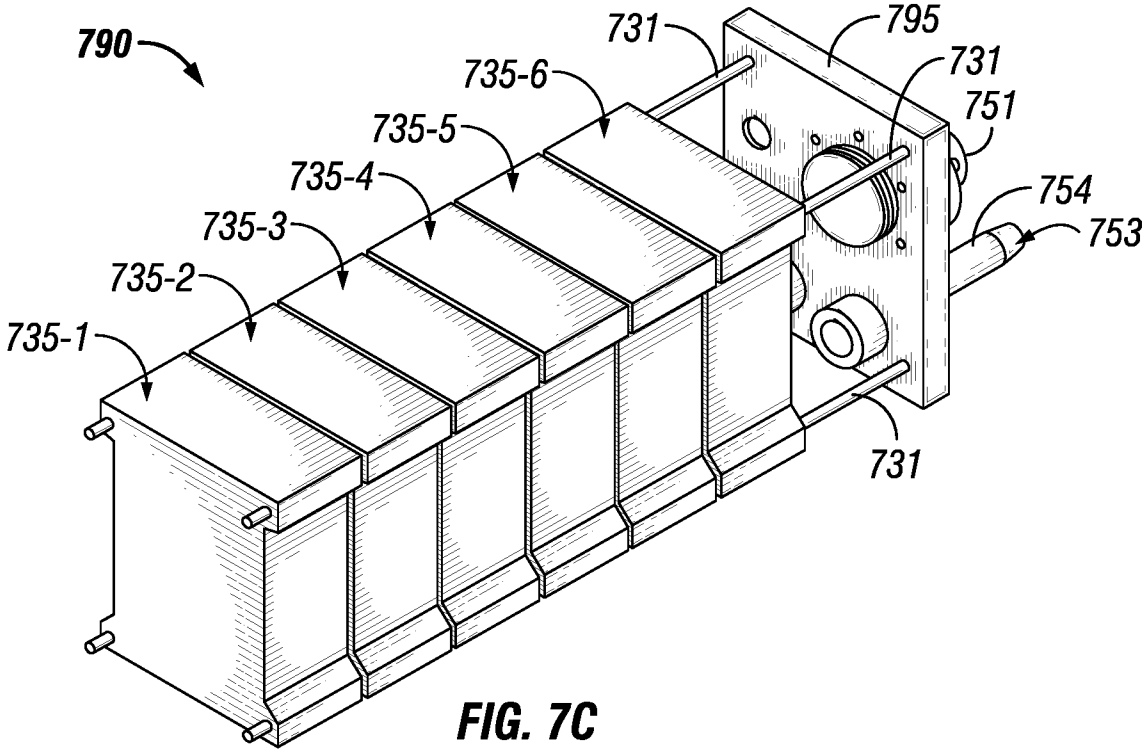

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735-4
735-3
735-2
735-1
754
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FIG. 7C

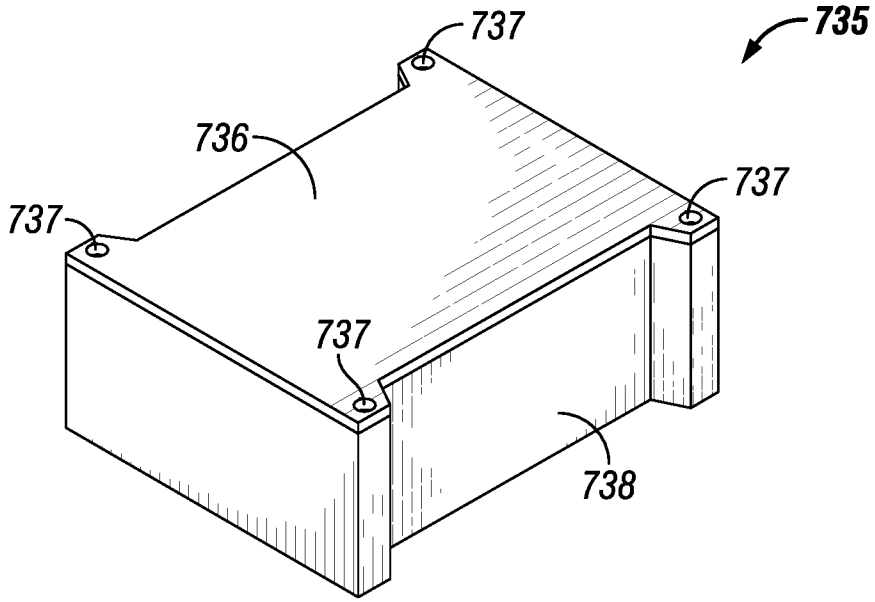

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FIG. 7D

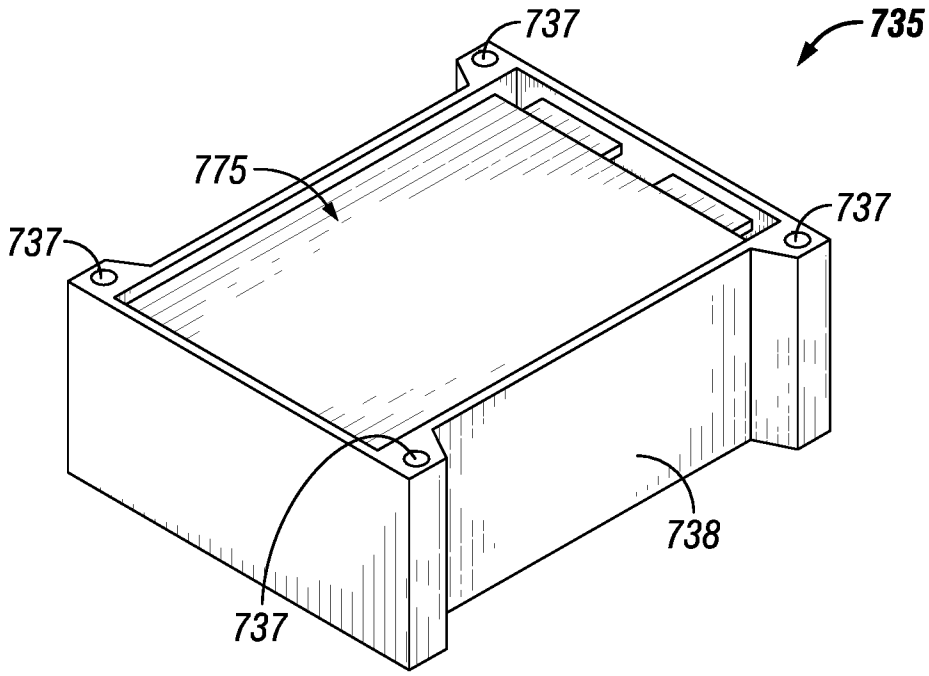


FIG. 7E

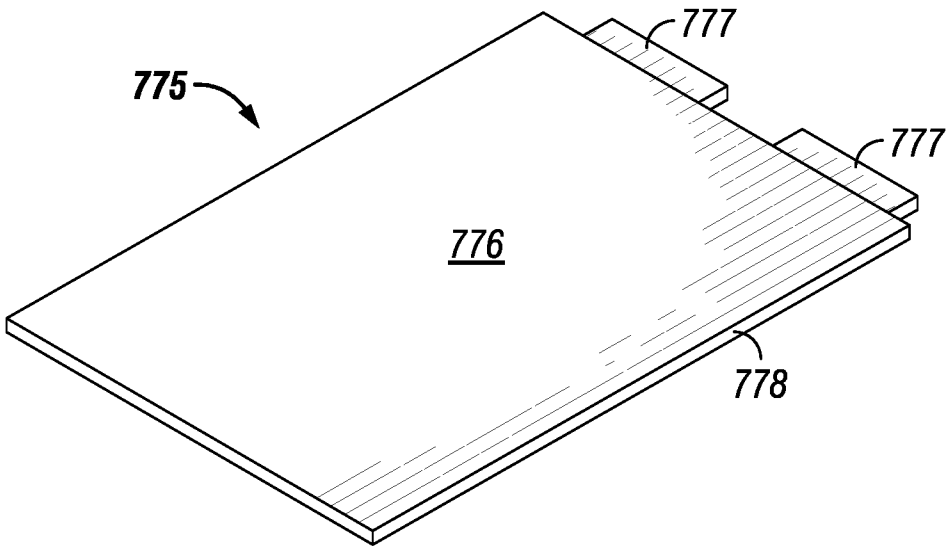


FIG. 7F

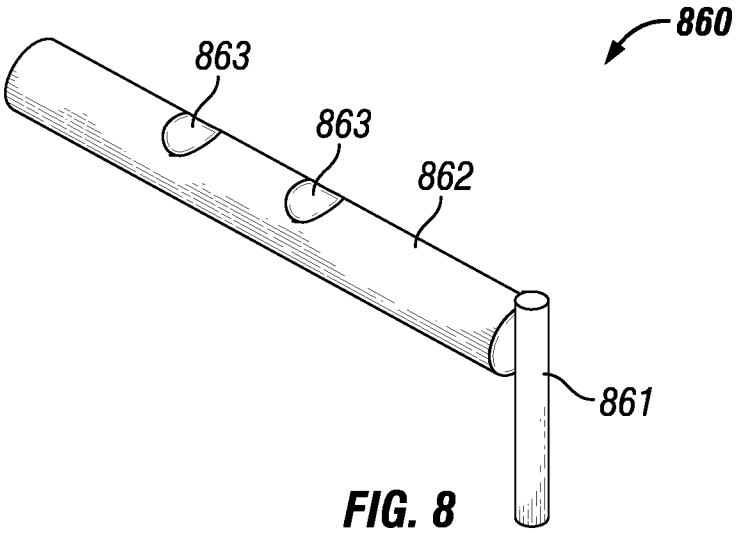

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FIG. 8

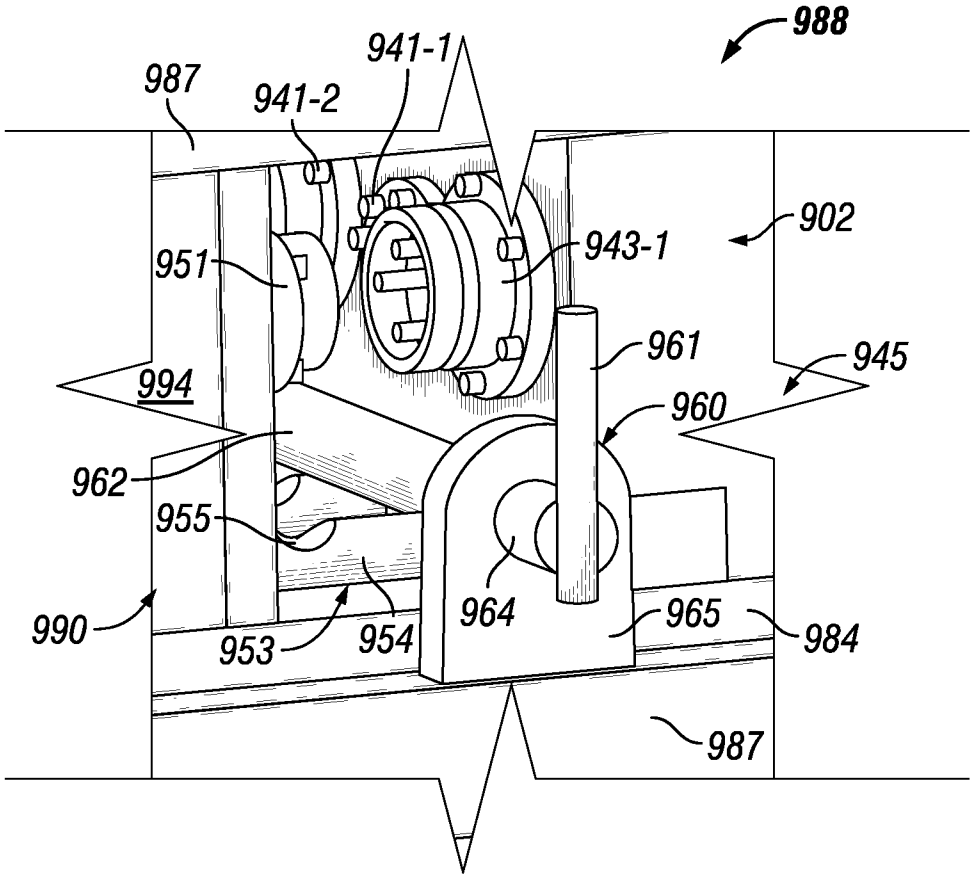

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FIG. 9A

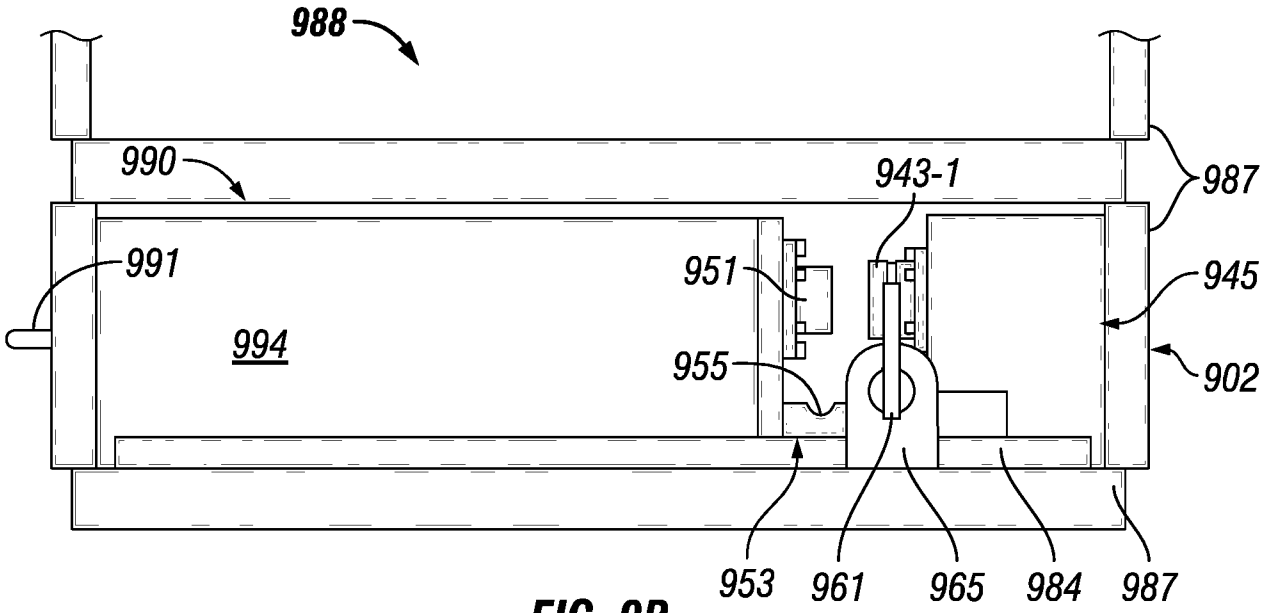

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FIG. 9B

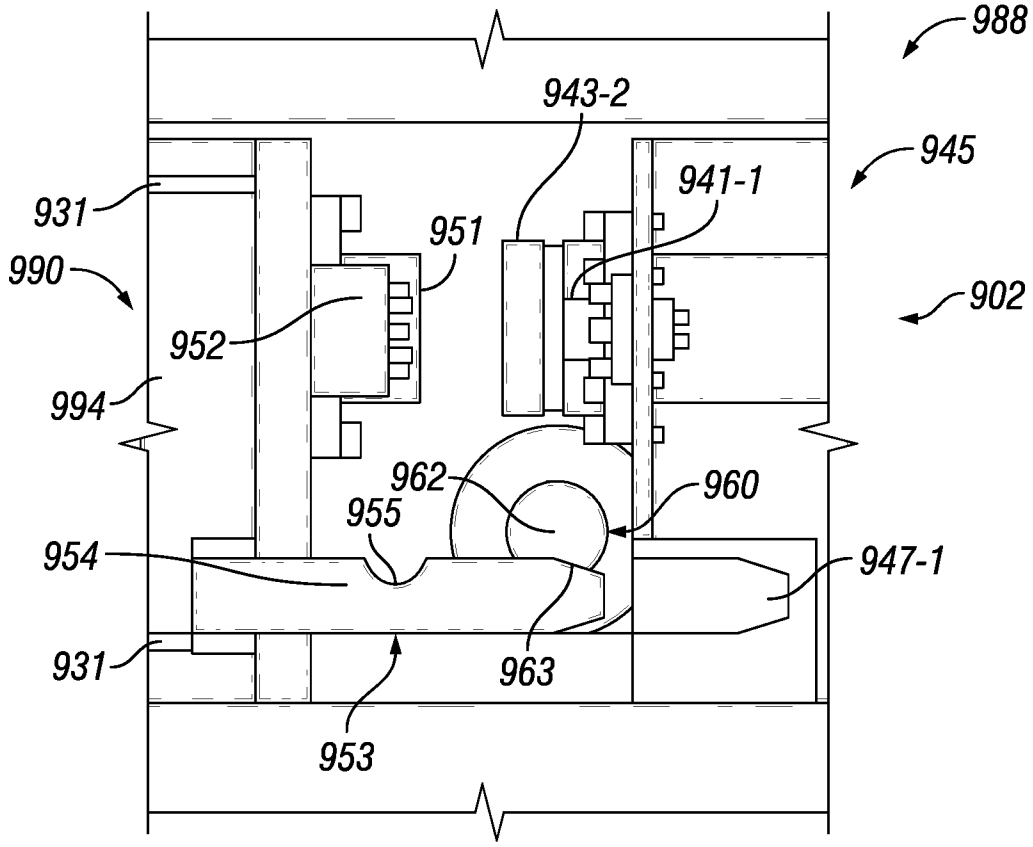

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FIG. 9C

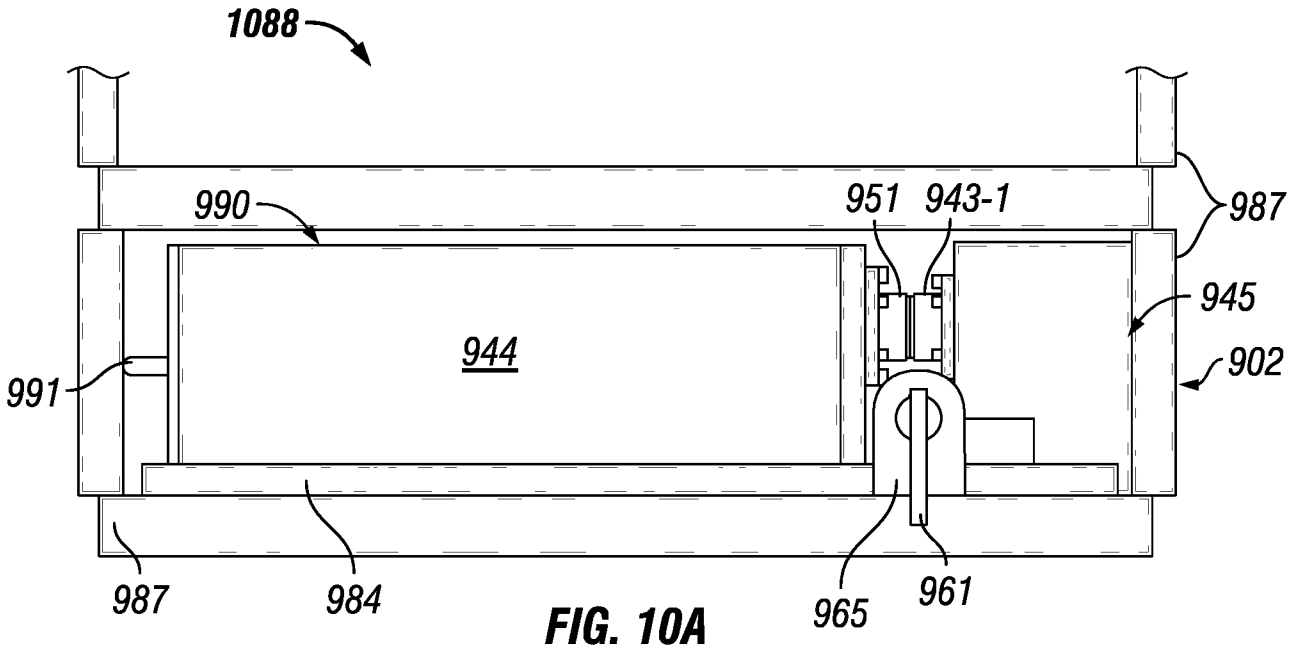


FIG. 10A

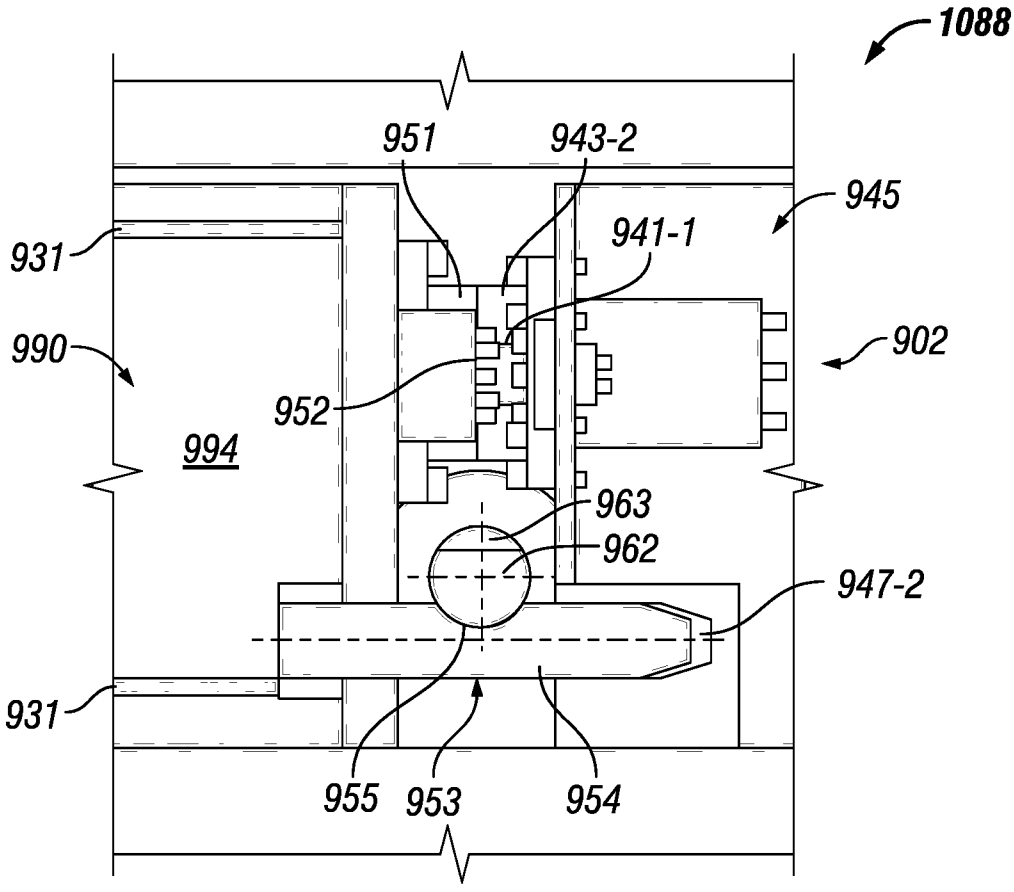


FIG. 10B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/056655

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H01M 10/46 (2017.01)

CPC - B63C 11/52; E21B 34/06; H01M 2/10; H01M 2/20; H01M 10/46; H01R 24/00; H02B 7/00; H02J 7/00 (2017.08)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

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

USPC - 361/602 (keyword delimited)

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/0042975 A1 (EAGLEPICHER TECHNOLOGIES LLC) 13 February, 2014 (13.02.2014) entire document	1, 11, 12
Y		2-10, 13-20
Y	US 2014/0370367 A1 (DENSO CORPORATION) 18 December 2014 (18.12.2014) entire document	2, 16
Y	US 2013/0286546 A1 (SCHNEIDER ELECTRIC INDUSTRIES SAS) 31 October 2013 (31.10.2013) entire document	3-10, 15, 18, 19
Y	US 9,039,454 B2 (YAZAKI CORPORATION) 26 May 2015 (26.05.2015) entire document	6-10
Y	EP 0184358 B1 (GEORGE BLAIR P.L.C.) 24 May 1989 (24.05.1989) entire document	6-10
Y	SeaSafe® Autonomous, Smart Battery Modules (Southwest Electronic Energy Corp; https://www.swe.com/seasafe-subsea-modules/) 23.September.2014 (23.09.2014) entire document	13, 14
Y	US 8,940,421 B2 (ZHAO et al) 27 January 2015 (27.01.2015) entire document	17
Y	US 2014/0144649 A1 (ARRAZOLA et al) 29 May 2014 (29.05.2014) entire document	20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 November 2017	26 DEC 2017
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (January 2015)