



(51) International Patent Classification:

E21B 33/035 (2006.01) *H02M 5/00* (2006.01)
E21B 43/01 (2006.01) *H02M 5/451* (2006.01)
F04D 13/00 (2006.01) *H02P 27/04* (2016.01)
F04D 13/08 (2006.01) *H02P 27/06* (2006.01)

(21) International Application Number:

PCT/US2017/056649

(22) International Filing Date:

13 October 2017 (13.10.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/421,623 14 November 2016 (14.11.2016) US

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(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,

(54) Title: SUBSEA VARIABLE FREQUENCY DRIVE AND MOTOR ASSEMBLY

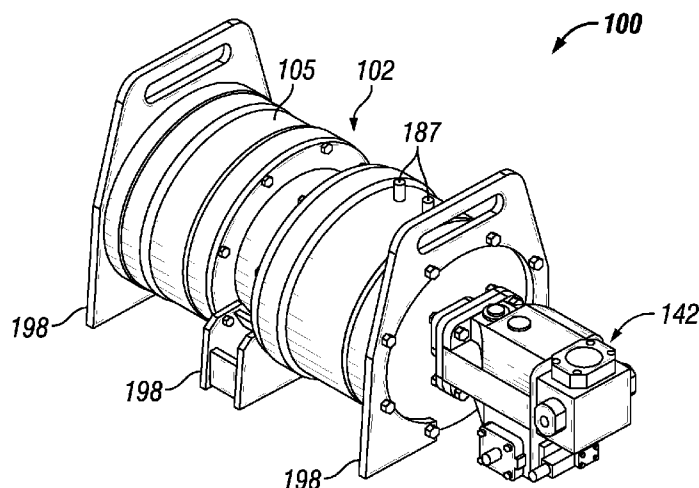


FIG. 1B

(57) Abstract: An electric assembly is described herein. The electric assembly can include a housing having at least one wall that forms a cavity, where the housing is rated for subsea conditions. The electric assembly can also include at least one motor disposed within the cavity. The electric assembly can further include at least one controller disposed with the cavity and coupled to the at least one motor, where the at least one controller controls the at least one motor.



EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

SUBSEA VARIABLE FREQUENCY DRIVE AND MOTOR ASSEMBLY

TECHNICAL FIELD

[0001] The present disclosure relates generally to subsea field operations, and more specifically to variable frequency drives (VFDs) and motor assemblies for use subsea.

BACKGROUND

[0002] In subterranean field operations, particularly in a subsea environment, economies are vitally important. Being able to perform a function while reducing space, power consumption, weight, and/or any other similar aspect for equipment or an assembly can result in significant savings of time, money, and other valuable resources. Currently, in subsea field operations, motors and related equipment, such as VFDs and controllers, have a large footprint, require interaction with surface equipment (which necessitates the use of long umbilical cables), and are not very efficient. Consequently, the use of motors and related equipment in subsea field operations currently used in the art results in high costs, time consuming installation, and extended down time during outage conditions.

SUMMARY

[0003] In general, in one aspect, the disclosure relates to an electric assembly for use in a subsea field operation. The electric assembly can include a housing having at least one wall that forms a first cavity and a second cavity, where the housing is rated for subsea conditions. The electric assembly can also include at least one motor disposed within the first cavity. The electric assembly can further include at least one controller disposed within the second cavity and coupled to the at least one motor, where the at least one controller controls the at least one motor. The first cavity and the second cavity can be physically separated from each other within the housing.

[0004] In another aspect, the disclosure can generally relate to a system that includes an electric assembly and a mechanical device. The electric assembly of the system can include a housing having at least one wall that forms a first cavity and a second cavity, where the housing is rated for subsea conditions. The electric assembly of the system can also include at least one motor disposed within the first cavity. The electric assembly of the system can further include a drive mechanism coupled to the at least one

motor, where the drive mechanism is disposed, at least in part, within the first cavity. The electric assembly of the system can also include at least one controller disposed within the second cavity and coupled to the at least one motor, where the at least one controller controls the at least one motor. The mechanical device of the system can be coupled to the drive mechanism, where the drive mechanism is propelled by the at least one motor and operates the mechanical device. The first cavity and the second cavity can be physically separated from each other within the housing of the electric assembly.

[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 VFD and motor assembly and are therefore not to be considered limiting of its scope, as subsea VFD and motor assemblies 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-1C show a VFD and motor assembly in accordance with certain example embodiments.

[0008] Figures 2A and 2B show various views of internal components of the VFD and motor assembly of Figures 1A-1C in accordance with certain example embodiments.

[0009] Figure 3 shows a motor of a VFD and motor assembly of in accordance with certain example embodiments.

[0010] Figure 4 shows a motor assembly of a VFD and motor assembly in accordance with certain example embodiments.

[0011] Figures 5A and 5B show a system diagram of a system that includes a VFD and motor assembly in accordance with certain example embodiments.

[0012] Figure 6 shows a computing device in accordance with certain example embodiments.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0013] The example embodiments discussed herein are directed to systems, apparatuses, and methods of subsea VFD and motor assemblies. While the example subsea VFD and motor assemblies described herein are directed toward subsea field operations, example subsea VFD and motor assemblies are not limited to subsea field operations. Examples of other applications that can be used with example subsea VFD and motor assemblies can include, but are not limited to, land-based field operations, above sea-level operations, and industrial operations.

[0014] The subsea VFD and motor assemblies (or components thereof) described herein can be made of one or more of a number of suitable materials to allow the subsea VFD and motor assemblies 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 VFD and motor assemblies can be exposed. Examples of such materials can include, but are not limited to, aluminum, stainless steel, fiberglass, glass, plastic, ceramic, and rubber.

[0015] Any portions of example subsea VFD and motor assemblies described herein can be made from a single piece (as from a mold). When an example subsea VFD and motor assembly 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 VFD and motor assembly (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.

[0016] 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” or a “coupling device” 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 VFD and motor assembly) can be made of one or more of a number of suitable materials, including but not limited to metal, ceramic, rubber, and plastic.

[0017] A coupling feature (including a complementary coupling feature) as described herein can allow one or more components and/or portions of an example subsea VFD and motor assembly to become mechanically coupled, directly or indirectly, to another portion of the subsea VFD and motor assembly. 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 VFD and motor assembly can be coupled to another portion of a subsea VFD and motor assembly by the direct use of one or more coupling features.

[0018] In addition, or in the alternative, a portion of an example subsea VFD and motor assembly can be coupled to another portion of the subsea VFD and motor assembly using one or more independent devices that interact with one or more coupling features disposed on a component of the subsea VFD and motor assembly. 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.

[0019] 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.

[0020] 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.

[0021] In the foregoing figures showing example embodiments of subsea VFD and motor assemblies, one or more of the components shown may be omitted, repeated, and/or substituted. Accordingly, example embodiments of subsea VFD and motor assemblies 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.

[0022] Example embodiments of subsea VFD and motor assemblies are described more fully hereinafter with reference to the accompanying drawings, in which example embodiments of subsea VFD and motor assemblies are shown. Subsea VFD and motor assemblies 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 VFD and motor assemblies 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.

[0023] Terms such as “first”, “second”, “top”, “bottom”, “proximal”, “distal”, “inner”, “outer”, “end”, “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 VFD and motor assemblies. 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.

[0024] Figures 1A-1C show a system 100 that includes a VFD and motor assembly 102 in accordance with certain example embodiments. Specifically, Figures 1A and 1B show a front-top-side perspective view of the system 100. Figure 1C shows a top view of

the system 100. In addition to the VFD and motor assembly 102, the system 100 of Figures 1A-1C includes one or more mechanical devices 142. In this case, the mechanical device 142 is a subsea hydraulic pump. The mechanical device 142 is mechanically coupled to the VFD and motor assembly 102 so that mechanical energy, derived from electric energy generated by the VFD and motor assembly 102, can be transferred to the mechanical device 142 and propel the mechanical device 142 into operation.

[0025] The VFD and motor assembly 102 can include a housing 103, where the housing 103 is at least one wall that forms a cavity, inside of which are disposed a number of components of the VFD and motor assembly 102 (as described below). In addition, the VFD and motor assembly 102 can include one or more mounting devices 198, one or more temperature control devices 172, and one or more fluid lines 187. The mounting devices 198 can be used to stabilize and/or secure the system 100 (or at least the VFD and motor assembly 102) to an object (e.g., a frame, a platform).

[0026] The mounting devices 198 can be coupled to various portions of the housing 103. For example, in this case, there are three mounting devices 198, with one mounting device 198 at one end (e.g., a distal end) of the VFD and motor assembly 102, one mounting device 198 at the opposite end (e.g., a proximal end) of the VFD and motor assembly 102, and the third mounting device 198 in the approximate middle (along the length) of the VFD and motor assembly 102. A mounting device 198 can have any of a number of characteristics (e.g., form, shape, size, coupling features). In this case, the mounting device 198 coupled to each end of the VFD and motor assembly 102 is a bracket that surrounds the housing 103, and the third mounting device 198 is a platform that abuts against the bottom third of the housing 103.

[0027] The temperature control device 172 shown in Figure 1C is a heat exchanger that is mounted against the distal end of the housing 103 of the VFD and motor assembly 102. The fluid lines 187 shown in Figures 1A-1C connect to the top of the housing 103 proximate to where the one or more motors are located within the housing 103. The fluid lines 187 can carry any type of fluid (e.g., water, oil) from one component of the VFD and motor assembly 102 to another component. The fluid that flows through the fluid lines 187 can be used to control one or more parameters (e.g., pressure, temperature) within the housing 103 of the VFD and motor assembly 102. More details about temperature control devices, such as temperature control device 172 of Figure 1C, and pressure regulating devices (not shown here) are provided below with respect to Figures 5A and 5B.

[0028] As discussed above, example VFD and motor assemblies, such as VFD and motor assembly 102 of Figures 1A-1C, can be used in certain harsh environments, such as subsea and marine environments. When used subsea, because of the size of motors currently used in the art, large inductors are located slightly above the water surface (for example, on a submersible or semi-submersible drilling rig) to provide power, using a very long cable, to a motor on the seabed. The motor can then be used to operate a mechanical device (e.g., a pump) on the seabed. A few problems persist with the systems currently used in the art.

[0029] For example, the assembly of the motor and the mechanical device cannot be tested under pressure before being put into service subsea. As a result, a great deal of time, manpower, and cost can be incurred to install equipment on the seabed, only to discover that the equipment is not functioning properly under the subsea conditions. As another example, very large size cable must be run from the operating platform at the water surface to the seabed, often covering a distance of hundreds or even thousands of feet. This high gauge cable is very expensive, heavy, and difficult to manipulate. As yet another example, there is no redundancy with systems currently used in the art. In other words, if one component (e.g., the motor) fails, the entire system is offline until the component is replaced. As will be explained below, example VFD and motor assemblies described herein can overcome these problems that exist with the systems currently used in the art.

[0030] Figures 2A and 2B show a system 200 that includes various views of internal components of the VFD and motor assembly 102 of Figures 1A-1C in accordance with certain example embodiments. Specifically, Figure 2A shows a front-top-side perspective view of the system 200. Figure 2B shows a cross-sectional side view of the system 200. Referring to Figures 1A-2B, the system 200 of Figures 2A and 2B show all of the features described above with respect to Figures 1A-1C, plus the following additional components of the VFD and motor assembly 102.

[0031] As discussed above, the housing 103 of the VFD and motor assembly 102 includes one or more walls that form one or more cavities (e.g., cavity 201, cavity 248). In certain example embodiments, one or more components of the VFD and motor assembly 102 are disposed within the cavity 201 and/or the cavity 248. Examples of such components can include, but are not limited to, a controller 204 (which can be or include a VFD), one or more motors 290, one or more temperature control devices 272, one or more

pressure regulating devices 274, one or more fluid lines 287, one or more signal transfer links 205, one or more power transfer links 285, one or more sensors 260, one or more switches, an alternating current (AC)-to-direct current (DC) converter (also called an AC/DC converter), a DC/DC converter, and a mechanical energy transfer device 286. These various components of the VFD and motor assembly 102 are described in more detail below with respect to Figures 3-5B.

[0032] In this example, the controller 204 is disposed in one cavity 248 of the housing 203, and the motors 290 are all disposed within another cavity 201 of the housing 203. When the housing 203 of example embodiments includes multiple cavities (as with cavity 201 and cavity 248 of Figures 2A and 2B), then the cavities can be physically separated from each other. In such a case, the environment (e.g., pressure, temperature) within each cavity of the housing 203 can be independently monitored and/or controlled. For example, the controller 204 can maintain the pressure within the cavity 201 to be approximately the same as the pressure in a subsea environment in which the VFD and motor assembly 102 is or will be located, while the controller 204 can maintain the pressure within the cavity 248 to be approximately one atmosphere. As a result, any number of any components (e.g., sensors 260, temperature control devices 272, pressure regulating devices 274, fluid lines 287) of the VFD and motor assembly 102 can be located in one or more cavities of the housing 203.

[0033] The controller 204 and the motors 290 are coupled to each other using the signal transfer links 205 and/or the power transfer links 285. In addition, since the VFD and motor assembly 102 can include pressure regulating devices 274, the VFD and motor assembly 102 (or portions thereof) can be tested (for example on a platform above water) under pressure (e.g., a pressure that simulates a subsea pressure) before being put into service in a subsea environment. Current accumulator-based approaches that deliver pressurized fluid cannot be tested in this way, which significantly increases the risk of defects being discovered during operation.

[0034] Further, because of the configuration of the example VFD and motor assembly 102, all of the wiring (in this case, the signal transfer links 205 and the power transfer links 285) between the controller 204 and the motors 290 are disposed in the body of the housing 203 between cavity 201 and cavity 248. Consequently, the signal transfer links 205 and the power transfer links 285 are not exposed to elements outside of the housing 203 (or, in some cases, to elements within cavity 201 and/or cavity 248), making

them protected and reducing one aspect of failure that exists with currently-used VFD and motor assemblies. In a subsea deployable embodiment, the cavity 201 containing the motors 290 can be pressure balanced with the surrounding water, while the cavity 248 containing the controller 204 can be kept at one atmosphere (or some other different pressure relative to the pressure of the cavity 201).

[0035] In this example, the VFD and motor assembly 102 includes two motors 290 (motor 290-1 and motor 290-2). These two motors 290 are aligned in series with each other along the same central axis, which coincides with the mechanical energy transfer device 286. The mechanical energy transfer device 286 receives mechanical energy from the motors 290, and this mechanical energy is transferred to the mechanical device 242, which is also coupled to the mechanical energy transfer device 286. The mechanical energy transfer device 286 can include a shaft (as in this example), a belt, a gear, a pulley, and/or any other suitable device or component that can transfer mechanical energy from the motors 290 to the mechanical devices 242. Further, the mechanical energy transfer device 286 can include one or more of a number of features to complement features of the motors 290 and/or the mechanical device 242. For example, the portion of the mechanical energy transfer device 286 that couples to the motors 290 can have one or more of a number of coupling features (e.g., teeth) disposed along the outer surface of the mechanical energy transfer device 286 to complement coupling features (e.g., coupling features 393 of Figure 3 below) of the motor. Both motor 290-1 and motor 290-2 are coupled to and controlled by the controller 204. Both motors 290 can operate simultaneously and synchronously with each other. Alternatively, one motor 290 (e.g., motor 290-1) can be controlled and operated independently of the other motor 290 (e.g., motor 290-2).

[0036] Under this latter situation, the reliability and longevity of the VFD and motor assembly 102 increases dramatically relative to currently-used VFD and motor assemblies. For example, the multiple motors 290 can operate in alternating cycles (e.g., periods of time) so that when one motor 290 (e.g., motor 290-1) is operating, the other motor 290 (e.g., motor 290-2) can be idle, and vice versa. In this way, the operating hours of each motor 290 are reduced to provide the same amount of mechanical energy (relative to currently-used VFD and motor assemblies) to the mechanical devices 142. This increases the useful life of the motors 290 and increases the amount of time between maintenance cycles.

[0037] As another example, when a VFD and motor assembly 102 has multiple motors 290, if one of the motors 290 (e.g., motor 290-1) fails, the other motor 290 (e.g., motor 290-2) can continue operating so that the mechanical devices 142 continually receive the mechanical energy they need, thereby avoiding unnecessary down time. This allows for a more efficient and continuous operation, and maintenance that would otherwise be instantaneous and mandatory for currently-used VFD and motor assemblies becomes a maintenance item that can be deferred using example VFD and motor assemblies 102.

[0038] Figure 3 shows a motor 390 of a VFD and motor assembly of in accordance with certain example embodiments. Referring to Figures 1A-3, example embodiments can use one or more of any type of motors. For example, a motor 390 can be an AC induction motor, which produces torque by the reaction between a varying magnetic field generated in the stator and the current induced in the coils of the rotor. However, using such an AC induction motor has a large footprint and high weight without the benefit of high power and torque densities.

[0039] As another example, as shown in Figure 3, a motor 390 can be an axial flux electrical motor. An axial flux electrical motor is a low speed, high torque motor that works well in direct drive applications, such as the applications that example VFD and motor assemblies can be used. More specifically, an axial flux electrical motor is a rotating self-synchronous machine with a permanent magnet DC rotor and electronic commutation of the stator coils providing rotational movement and torque. Further, an axial flux electrical motor has less weight and size for a given power output compared with an induction motor.

[0040] In addition, an axial flux electrical motor can be configured with a yokeless and segmented armature topology that is compact, less complex to manufacture, and produces high power and torque densities. Further, as shown in Figures 2A and 2B above, because of the relatively compact size of axial flux electrical motors, when an axial flux electrical motor is used in example embodiments, multiple motors 390 can be used. Figure 4 below shows detail of how multiple motors 390 can be configured in example embodiments.

[0041] The motor 390 of Figure 3 can include one or more of a number of features and/or components. For example, the axial flux electrical motor 390 of Figure 3 has a housing 392 that has a thickness 381 and a diameter 382 (which in this case, because of

the circular shape of the motor 390, represents the width and height) relative to a central axis 366. There is an aperture 394, centered around the central axis 366, that traverses the thickness 381 of the housing 392 of the motor 390 and is defined by a number of coupling features 393 (in this case, teeth) that receive a shaft, as shown in Figure 4 below.

[0042] The motor 390 can also include one or more ports 391 that extend from the housing 392 (in this case, at the top of the housing 392). These ports 391 can be coupled to fluid lines (e.g., fluid lines 287) that allow for temperature control (e.g., cooling) of the components of the motor 390 disposed within the housing during operation. Further, the motor 390 can include a junction box 395 that houses one or more electrical terminals (as shown in Figure 4 below) to which one or more signal transfer links 205 and/or power transfer links 285 can be coupled.

[0043] Further, the housing 392 can include one or more coupling features 396 that allow the motor 390 to be coupled to one or more other components (e.g., the housing 103 of the VFD and motor assembly 102, another motor 390) of the VFD and motor assembly 102. The coupling features 396 of the motor 390 in this case are apertures that traverse the thickness 381 of the housing 392 and are disposed along the outer perimeter of the housing 392. The motor 390 of Figure 3 has 8 coupling features 396 that are disposed substantially equidistantly from each other relative to the central axis 366.

[0044] Figure 4 shows a motor assembly 465 of a VFD and motor assembly in accordance with certain example embodiments. Referring to Figures 1A-4, the motor assembly 465 of Figure 4 includes two motors 490 (motor 490-1 and motor 490-2) that are disposed next to each other in series. Motor 490-1 and motor 490-2 are substantially similar to the motor 390 of Figure 3, except that in this case, the housing 392 and the junction box 395 shown in Figure 3 are removed from both motors 490 of Figure 4. In this case, motor 490-1 and motor 490-2 abut against each other and share a mechanical energy transfer device 486 that traverses each aperture (hidden from view by the mechanical energy transfer device 486) along the central axis of the motors 490.

[0045] Motor 490-1 and motor 490-2 can be coupled to each other, directly or indirectly, using the coupling features of the housing, as described above with respect to Figure 3. The labeled components of Figure 4 that are associated with motor 490-1 and with “-1”, and the labeled components of Figure 4 that are associated with motor 490-2 and with “-2”. For example, the ports 491 of motor 490-2 are ports 491-2. As another example, the electrical terminals 497 of motor 490-1 are electrical terminals 497-1.

[0046] Figures 5A and 5B show a system diagram of a subsea system 500 that includes a VFD and motor assembly 502 in accordance with certain example embodiments. Specifically, Figure 5A shows the subsea system 500, and Figure 5B shows a detailed system diagram of a controller 504. The controller 504 of Figures 5A and 5B can be, or can include, a VFD. As shown in Figures 5A and 5B, the subsea system 500 can include a power supply 540, a mechanical device 542, a user 550, a network manager 580, and at least one VFD and motor assembly 502. In addition to the controller 504, the VFD and motor assembly 502 can include one or more sensors 560 (also sometimes called sensor modules 560 or sensor devices 560), one or more switches 570, one or more temperature control devices 572, one or more pressure regulating devices 574, one or more motors 590 (e.g., motor 190-1, motor 190-N), one or more alternating current (AC)-to-direct current (DC) converters 545 (also called, for example, AC/DC converters 545), and one or more DC/DC converters 549.

[0047] As shown in Figure 5B, the controller 504 can include one or more of a number of components. Such components, can include, but are not limited to, a control engine 506, a communication module 508, a timer 510, an energy metering module 511, a power module 512, a storage repository 530, a hardware processor 520, a memory 522, a transceiver 524, an application interface 526, and, optionally, a security module 528. The components shown in Figures 5A and 5B are not exhaustive, and in some embodiments, one or more of the components shown in Figures 5A and 5B may not be included in an example VFD and motor assembly 502.

[0048] Further, one or more components shown in Figures 5A and 5B can be rearranged. For example, one or more of the switches 570 can be part of the controller 504 of Figure 5B. As another example, there can be multiple local controllers 504 that are part of one or more of the motors 590 and perform at least a portion of the functions of the controller 504, as described below. Any component of the example VFD and motor assembly 502 can be discrete or combined with one or more other components of the VFD and motor assembly 502.

[0049] A user 550 may be any person that interacts with subsea systems or other devices that use example VFD and motor assemblies. Examples of a user 550 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 550 can use a user system (not shown), which may include a display (e.g., a GUI). The user 550 interacts with (e.g., sends data to, receives data from) the controller 504 (including portions thereof and/or other components) of the VFD and motor assembly 502 via the application interface 526 (described below). The user 550 can also interact with a network manager 580, the power supply 540, and the mechanical device 542. Interaction between the user 550 and the VFD and motor assembly 502, the network manager 580, the power supply 540, and the mechanical device 542 can be conducted using signal transfer links 505 and/or power transfer links 585.

[0050] Each signal transfer link 505 and each power transfer link 585 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 505 can be (or include) one or more electrical conductors that are coupled to the VFD and motor assembly 502 and to a sensor 560. A signal transfer link 505 can transmit signals (e.g., communication signals, control signals, data) between the VFD and motor assembly 502 and the user 550, the network manager 580, the power supply 540, and the mechanical device 542. Similarly, a power transfer link 585 can transmit power between the VFD and motor assembly 502 and the user 550, the network manager 580, the power supply 540, and the mechanical device 542.

[0051] In some cases, a signal transfer link 505 and a power transfer link 585 can be or use the same wired and/or wireless equipment. One or more signal transfer links 505 and/or one or more power transfer links 585 can also transmit signals and power, respectively, between components (e.g., controller 504, sensor 560, switch 570) of the VFD and motor assembly 502.

[0052] The network manager 580 is a device or component that can communicate with the VFD and motor assembly 502. For example, the network manager 580 can send instructions to the controller 504 of the VFD and motor assembly 502 as to when certain switches 570 should be operated (change state). As another example, the network manager 580 can receive data (e.g., run time, current flow) associated with the operation of each motor 190 of the VFD and motor assembly 502 to determine when maintenance should be performed on the VFD and motor assembly 502 or portions thereof.

[0053] The one or more sensors 560 can be any type of sensing device that measure one or more parameters. Examples of types of sensors 560 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 560 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 560 can be used to operate one or more motors 590 of the VFD and motor assembly 502. Alternatively, a sensor 560 can be used to operate, directly or indirectly, some other component (e.g., temperature control device 572, pressure regulating device 574) of the VFD and motor assembly 502.

[0054] Each sensor 560 can use one or more of a number of communication protocols. A sensor 560 can be associated with the VFD and motor assembly 502 in the system 500. A sensor 560 can be located within the cavity 501 and/or the cavity 548 formed by the housing 503 of the VFD and motor assembly 502, disposed on the housing 503 of the VFD and motor assembly 502, or located outside the housing 503 of the VFD and motor assembly 502.

[0055] The user 550, the network manager 580, the power supply 540, and/or the mechanical device 542 can interact with the controller 504 of the VFD and motor assembly 502 using the application interface 526 in accordance with one or more example embodiments. Specifically, the application interface 526 of the controller 504 receives data (e.g., information, communications, instructions, updates to firmware) from and sends data (e.g., information, communications, instructions) to the user 550, the network manager 580, the power supply 540, and/or the mechanical device 542. The user 550, the network manager 580, the power supply 540, and/or the mechanical device 542 can include an interface to receive data from and send data to the controller 504 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.

[0056] The controller 504, the user 550, the network manager 580, the power supply 540, and/or the mechanical device 542 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 504. 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 6.

[0057] 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 500.

[0058] As discussed above, the VFD and motor assembly 502 can include a housing 503. Also as discussed above, the housing 503 can include at least one wall that forms one or more cavities (*e.g.*, cavity 501, cavity 548). Similarly, one or more other components (*e.g.*, the controller 504, switches 570) of the VFD and motor assembly 502 can be disposed within or on the housing 503. For example, the controller 504 can be located within cavity 548 of the housing 503, and the motors 590 can be located within cavity 501 of the housing 503. In some cases, the housing 503 of the VFD and motor assembly 502 can be designed to comply with any applicable standards so that the VFD and motor assembly 502 (or portions thereof) can be located in a particular environment (*e.g.*, subsea, marine).

[0059] The housing 503 of the VFD and motor assembly 502 can be used to house one or more components of the VFD and motor assembly 502, including one or more components of the controller 504. As discussed above, the controller 504 in this example includes the control engine 506, the communication module 508, the timer 510, the energy metering module 511, the power module 512, the storage repository 530, the hardware

processor 520, the memory 522, the transceiver 524, the application interface 526, and the optional security module 528. In alternative embodiments, any one or more of these or other components of the VFD and motor assembly 502 can be disposed on the housing 503 and/or remotely from the housing 503.

[0060] The storage repository 530 can be a persistent storage device (or set of devices) that stores software and data used to assist the controller 504 in communicating with the user 550, the network manager 580, the power supply 540, and/or the mechanical device 542 within the system 500. In one or more example embodiments, the storage repository 530 stores one or more protocols 532, algorithms 533, and stored data 534. The protocols 532 can be any of a number of protocols that are used to send and/or receive data between the controller 504 and components (e.g., the user 550, the network manager 580) external to the VFD and motor assembly 502 and components (e.g., one or more sensors 560) internal to the VFD and motor assembly 502. The protocols 532 can also include processes and procedures that are not related to communications. For example, a protocol 532 can include a process for detecting, attempting to correct, and reporting a failure of a motor 190.

[0061] When a protocol 532 is used for communications, the protocol 532 can be used for wired and/or wireless communication. Examples of a protocol 532 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 532 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 wirelessHART protocol, and an International Society of Automation (ISA) 100 protocol. In this way, one or more of the protocols 532 can provide a layer of security to the data transferred within the system 500.

[0062] The algorithms 533 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 506 of the controller 504 follows based on certain conditions at a point in time. An example of an algorithm 533 is measuring (using the energy metering module 511), storing (using the stored data 534 in the storage repository 530), and evaluating the current and voltage delivered to and delivered by the AC/DC converter 545 to a motor 190 over time.

[0063] As another example, an algorithm 533 can be directed to continuously monitor the current (as measured by the energy metering module 511 and stored as stored data 534) output by each motor 190. If the level of current exceeds a threshold value, then one or more switches 570 can change state (e.g., using the control engine 506) to electrically isolate the motor 190. Alternatively, a protocol 532 can be used to direct the control engine 506 to operate one or more of the switches 570 based on some other factor, including but not limited to a passage of time.

[0064] Stored data 534 can be any data associated with the VFD and motor assembly 502 (including any components thereof), any measurements taken by the sensors 560, measurements taken by the energy metering module 511, time measured by the timer 510, threshold values, current ratings for the power supply 540, results of previously run or calculated algorithms, nameplate data of each motor 190, and/or any other suitable data. Such data can be any type of data, including but not limited to historical data for the VFD and motor assembly 502 (including any components thereof), performance of the temperature control devices 572, performance of the pressure regulating devices 574, calculations, measurements taken by the energy metering module 511, and measurements taken by one or more sensors 560. The stored data 534 can be associated with some measurement of time derived, for example, from the timer 510.

[0065] Examples of a storage repository 530 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 530 can be located on multiple physical machines, each storing all or a portion of the protocols 532, the algorithms 533, and/or the stored data 534 according to some example embodiments. Each storage unit or device can be physically located in the same or in a different geographic location.

[0066] The storage repository 530 can be operatively connected to the control engine 506. In one or more example embodiments, the control engine 506 includes functionality to communicate with the user 550, the network manager 580, the power supply 540, and the mechanical device 542 in the system 500. More specifically, the control engine 506 sends information to and/or receives information from the storage repository 530 in order to communicate with the user 550, the network manager 580, the power supply 540, and the mechanical device 542. As discussed below, the storage

repository 530 can also be operatively connected to the communication module 508 in certain example embodiments.

[0067] In certain example embodiments, the control engine 506 of the controller 504 controls the operation of one or more components (*e.g.*, the communication module 508, the timer 510, the transceiver 524) of the controller 504 and/or one or more components (*e.g.*, temperature control devices 572, pressure regulating devices 574, sensors 560) of another portion of the VFD and motor assembly 502. For example, the control engine 506 can activate the communication module 508 when the communication module 508 is in “sleep” mode and when the communication module 508 is needed to send data received from another component (*e.g.*, switches 570, a sensor 560, the user 550) in the system 500.

[0068] As another example, the control engine 506 can acquire the current time using the timer 510. The timer 510 can enable the controller 504 to control the VFD and motor assembly 502 (including any components thereof, such as one or more power supplies 540 and one or more switches 570) even when the controller 504 has no communication with the network manager 580. As yet another example, the control engine 506 can direct the energy metering module 511 to measure and send power consumption information of a power supply 540 to the network manager 580. In some cases, the control engine 506 of the controller 504 can control the position (*e.g.*, open, closed) of each switch 570 within the VFD and motor assembly 502.

[0069] The control engine 506 can be configured to perform a number of functions that control which motor 190 of the VFD and motor assembly 502 receives power from the power supply 540 and which motor 190 of the VFD and motor assembly 502 provides mechanical energy used by the mechanical device 542 system 500. Specifically, the control engine 506 can control the position of each of the switches 570, thereby controlling which particular motors 590 of the VFD and motor assembly 502 become isolated, which motor 190 receive power from the power supply 540 to generate mechanical energy, and/or which motor 190 is idle at a particular point in time. Further, for a motor 190 that receives power from the power supply 540, the controller 504 can dictate one or more operating parameters (*e.g.*, speed, voltage output) of the motor 590.

[0070] For example, the control engine 506 can execute any of the protocols 532 and/or algorithms 533 stored in the storage repository 530 and use the results of those protocols 532 and/or algorithms 533 to change the position of one or more switches 570.

As a specific example, the control engine 506 can measure (using the energy metering module 511), store (as stored data 534 in the storage repository 530), and evaluate, using an algorithm 533, the mechanical energy delivered by a motor 190 of the VFD and motor assembly 502 to the mechanical device 542 over time. In this way, the operation of each motor 190 of the VFD and motor assembly 502 can be optimized to increase the reliability of the motors 590.

[0071] As another specific example, the control engine 506 can determine, based on measurements made by the energy metering module 511, whether a particular motor 190 (or some other component) of the VFD and motor assembly 502 has failed. In such a case, the control engine 506 can change the position of one or more switches 570 to have another motor 590 of the VFD and motor assembly 502 provide mechanical energy, using the mechanical energy transfer device 586, to the mechanical device 542 that was receiving mechanical energy from the motor 590 of the VFD and motor assembly 502 that failed.

[0072] The control engine 506 can control the operation of one or more sensors 560 in the VFD and motor assembly 502. The control engine 506 can also use the measurements taken by the sensors 560 to control the operation of one or more components (e.g., a temperature control device 572, a pressure regulating device 574, a switch 570) of the VFD and motor assembly 502 at a particular point in time.

[0073] The control engine 506 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 VFD and motor assembly 502 (or component thereof) exceeds a threshold value, indicating possible present or future failure of the VFD and motor assembly 502 (or component thereof). The control engine 506 can further measure (using one or more sensors 560) and analyze any of a number of power (e.g., current, voltage, surges, faults, run time, speed) associated with the motors 590 over time. Using one or more algorithms 533, the control engine 506 can predict the expected useful life of the motors 590 (or other components of the VFD and motor assembly 502) based on stored data 534, a protocol 532, one or more threshold values, and/or some other factor. The control engine 506 can also measure (using one or more sensors 560) and analyze the efficiency of the VFD and motor assembly 502 (or component thereof) over time. An alarm can be generated by the control engine 506 when

the efficiency of the VFD and motor assembly 502 (or component thereof) falls below a threshold value, indicating failure of the VFD and motor assembly 502 (or component thereof).

[0074] In certain example embodiments, the control engine 506 can regulate the temperature and/or pressure within one or more cavities (e.g., cavity 501, cavity 548) and/or of any component of the VFD and motor assembly 502. For example, the control engine 506 can determine (based on a measurement made by a sensor 560 that measures temperature) whether to activate a heating circuit (a type of temperature control device 572) when the temperature of a motor 590 exceeds a high temperature threshold value. As another example, the control engine 506 can determine (based on a measurement made by a sensor 560 that measures temperature) whether to activate a cooling circuit (another type of temperature control device 572) when the temperature of the controller 504 falls below a low temperature threshold value. As yet another example, the control engine 506 can determine (based on a measurement made by a sensor 560 that measures pressure within the cavity 501 and/or the cavity 548) whether to activate a pressure regulating device 574 when the pressure falls outside of a range of acceptable pressure values.

[0075] The control engine 506 can provide power, control, communication, and/or other similar signals to the user 550, the network manager 580, the power supply 540, and the mechanical device 542. Similarly, the control engine 506 can receive power, control, communication, and/or other similar signals from the user 550, the network manager 580, the power supply 540, and the mechanical device 542. The control engine 506 can control each sensor 560 automatically (for example, based on one or more algorithms 533 stored in the storage repository 530) and/or based on power, control, communication, and/or other similar signals received from another device through a signal transfer link 505 and/or a power transfer link 585. The control engine 506 may include a printed circuit board, upon which the hardware processor 520 and/or one or more discrete components of the controller 504 are positioned.

[0076] In certain embodiments, the control engine 506 of the controller 504 can communicate with one or more components of a system external to the system 500 in furtherance of optimizing the performance of the motors 590 of the VFD and motor assembly 502. For example, the control engine 506 can interact with an inventory management system by ordering a component (e.g., a DC/DC converter 549, motor 190) of the VFD and motor assembly 502 to replace a component of the VFD and motor

assembly 502 that the control engine 506 has determined to fail or be failing. As another example, the control engine 506 can interact with a workforce scheduling system by scheduling a maintenance crew to repair or replace the VFD and motor assembly 502 (or component thereof) when the control engine 506 determines that the VFD and motor assembly 502 (or component thereof) requires maintenance or replacement. In this way, the controller 504 is capable of performing a number of functions beyond what could reasonably be considered a routine task.

[0077] In certain example embodiments, the control engine 506 can include an interface that enables the control engine 506 to communicate with one or more components (*e.g.*, a pressure regulating device 574, a switch 570) of the VFD and motor assembly 502. For example, if the VFD and motor assembly 502 operates under IEC Standard 62386, then the VFD and motor assembly 502 can have a serial communication interface that will transfer data (*e.g.*, stored data 534) measured by the sensors 560. In such a case, the control engine 506 can also include a serial interface to enable communication with one or more components within the system 500. Such an interface can operate in conjunction with, or independently of, the protocols 532 used to communicate between the controller 504 and the user 550, the network manager 580, the power supply 540, and the mechanical device 542.

[0078] The control engine 506 (or other components of the controller 504) 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 (I²C), and a pulse width modulator (PWM).

[0079] The communication module 508 of the controller 504 determines and implements the communication protocol (*e.g.*, from the protocols 532 of the storage repository 530) that is used when the control engine 506 communicates with (*e.g.*, sends signals to, receives signals from) the user 550, the network manager 580, the power supply 540, and/or one the mechanical device 542. In some cases, the communication module 508 accesses the stored data 534 to determine which communication protocol 532 is used to communicate with the sensor 560 associated with the stored data 534. In addition, the communication module 508 can interpret the communication protocol 532 of a

communication received by the controller 504 so that the control engine 506 can interpret the communication.

[0080] The communication module 508 can send and receive data between the network manager 580, the power supply 540, the mechanical device 542, and/or the users 550 and the controller 504. The communication module 508 can send and/or receive data in a given format that follows a particular protocol 532. The control engine 506 can interpret the data packet received from the communication module 508 using the protocol information stored in the storage repository 530. The control engine 506 can also facilitate the data transfer between one or more sensors 560 and the network manager 580, the power supply 540, the mechanical device 542, and/or a user 550 by converting the data into a format understood by the communication module 508.

[0081] The communication module 508 can send data (*e.g.*, protocols 532, algorithms 533, stored data 534, operational information, alarms) directly to and/or retrieve data directly from the storage repository 530. Alternatively, the control engine 506 can facilitate the transfer of data between the communication module 508 and the storage repository 530. The communication module 508 can also provide encryption to data that is sent by the controller 504 and decryption to data that is received by the controller 504. The communication module 508 can also provide one or more of a number of other services with respect to data sent from and received by the controller 504. Such services can include, but are not limited to, data packet routing information and procedures to follow in the event of data interruption.

[0082] The timer 510 of the controller 504 can track clock time, intervals of time, an amount of time, and/or any other measure of time. The timer 510 can also count the number of occurrences of an event, whether with or without respect to time. Alternatively, the control engine 506 can perform the counting function. The timer 510 is able to track multiple time measurements concurrently. The timer 510 can track time periods based on an instruction received from the control engine 506, based on an instruction received from the user 550, based on an instruction programmed in the software for the controller 504, based on some other condition or from some other component, or from any combination thereof.

[0083] The timer 510 can be configured to track time when there is no power delivered to the controller 504 (*e.g.*, the power module 512 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 504, the timer 510 can communicate any aspect of time to the controller 504. In such a case, the timer 510 can include one or more of a number of components (e.g., a super capacitor, an integrated circuit) to perform these functions.

[0084] The energy metering module 511 of the controller 504 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 549, output of each motor 590) associated with the VFD and motor assembly 502. The energy metering module 511 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 511 can measure a component of power continuously, periodically, based on the occurrence of an event, based on a command received from the control module 506, and/or based on some other factor.

[0085] The power module 512 of the controller 504 provides power to one or more other components (e.g., timer 510, control engine 506) of the controller 504. In addition, in certain example embodiments, the power module 512 can provide power to one or more other components (e.g. a sensor 560) of the VFD and motor assembly 502. The power module 512 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 512 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 512 can include one or more components that allow the power module 512 to measure one or more elements of power (e.g., voltage, current) that is delivered to and/or sent from the power module 512. Alternatively, the controller 504 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 504.

[0086] The power module 512 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 or other power transfer link 585) from a source external to the VFD and motor assembly 502 and generates power of a type (e.g., AC, DC) and level (e.g., 12V, 24V, 520V) that can be used by the other components of the controller 504 and/or the VFD and motor assembly 502. The power module 512 can use a closed control loop to maintain a preconfigured voltage or current with a tight tolerance at the output.

The power module 512 can also protect the rest of the electronics (e.g., hardware processor 520, transceiver 524) in the VFD and motor assembly 502 from surges generated in the line.

[0087] In addition, or in the alternative, the power module 512 can be a source of power in itself to provide signals to the other components of the controller 504 and/or the VFD and motor assembly 502. For example, the power module 512 can be a battery or battery system. As another example, the power module 512 can be a localized photovoltaic power system. The power module 512 can also have sufficient isolation in the associated components of the power module 512 (e.g., transformers, opto-couplers, current and voltage limiting devices) so that the power module 512 is certified to provide power to an intrinsically safe circuit.

[0088] In certain example embodiments, the power module 512 of the controller 504 can also provide power and/or control signals, directly or indirectly, to one or more of the sensors 560. In such a case, the control engine 506 can direct the power generated by the power module 512 to the sensors 560 of the VFD and motor assembly 502. In this way, power can be conserved by sending power to the sensors 560 of the VFD and motor assembly 502 when those devices need power, as determined by the control engine 506.

[0089] The hardware processor 520 of the controller 504 executes software, algorithms, and firmware in accordance with one or more example embodiments. Specifically, the hardware processor 520 can execute software on the control engine 506 or any other portion of the controller 504, as well as software used by the user 550, the network manager 580, the power supply 540, and/or the mechanical device 542. The hardware processor 520 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 520 is known by other names, including but not limited to a computer processor, a microprocessor, and a multi-core processor.

[0090] In one or more example embodiments, the hardware processor 520 executes software instructions stored in memory 522. The memory 522 includes one or more cache memories, main memory, and/or any other suitable type of memory. The memory 522 can include volatile and/or non-volatile memory. The memory 522 is discretely located within the controller 504 relative to the hardware processor 520 according to some example

embodiments. In certain configurations, the memory 522 can be integrated with the hardware processor 520.

[0091] In certain example embodiments, the controller 504 does not include a hardware processor 520. In such a case, the controller 504 can include, as non-exclusive examples, one or more field programmable gate arrays (FPGA), one or more 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 504 (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 520.

[0092] The transceiver 524 of the controller 504 can send and/or receive control and/or communication signals. Specifically, the transceiver 524 can be used to transfer data between the controller 504 and the user 550, the network manager 580, the power supply 540, and/or the mechanical device 542. The transceiver 524 can use wired and/or wireless technology. The transceiver 524 can be configured in such a way that the control and/or communication signals sent and/or received by the transceiver 524 can be received and/or sent by another transceiver that is part of the user 550, the network manager 580, the power supply 540, and/or the mechanical device 542. The transceiver 524 can use any of a number of signal types, including but not limited to radio signals.

[0093] When the transceiver 524 uses wireless technology, any type of wireless technology can be used by the transceiver 524 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 524 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 532 of the storage repository 530. Further, any transceiver information for the user 550, the network manager 580, the power supply 540, and/or the mechanical device 542 can be part of the stored data 534 (or similar areas) of the storage repository 530.

[0094] Optionally, in one or more example embodiments, the security module 528 secures interactions between the controller 504, the user 550, the network manager 580, the power supply 540, and/or the mechanical device 542. More specifically, the security module 528 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 550 to interact with the controller 504 and/or the sensors 560. Further, the security module 528 can restrict receipt of information, requests for information, and/or access to information in some example embodiments.

[0095] The mechanical device 542 of the system 500 can include one or more of any number of devices and/or components that can be operated using a mechanical energy transfer device 586 (described above with respect to Figures 2A and 2B) driven by the VFD and motor assembly 502. The system 500 can have one or more of any number and/or type of mechanical device 542. Examples of such a mechanical device 542 can include, but are not limited to, a fan, a pump (e.g., a hydraulic pump), a conveyer, and an impeller.

[0096] The power supply 540 of the VFD and motor assembly 502 provides power to the VFD and motor assembly 502. In particular, the power supply 540 provides power to the motors 590 so that the motors 590 can generate the mechanical energy used by the mechanical device 542. The power supply 540 can be substantially the same as, or different than, the power module 512 of the controller 504. The power supply 540 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 supply 540 may include a printed circuit board, upon which the microprocessor and/or one or more discrete components are positioned.

[0097] In certain example embodiments, the power supply 540 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 545 (and/or to some similar component of the VFD and motor assembly 502, such as a DC/DC converter 549). The AC/DC converter 545 receives the power from the power supply 540 and generates power of a type (e.g., AC, DC) and level (e.g., 12V, 24V, 520V) that can be used by the motors 590. In some cases, the power supply 540 can receive power from a source external to the VFD and motor assembly 502. In addition, or in the alternative, the power supply 540 can be a source of power in itself. For example, the power supply 540 can be a battery (or battery system), a localized photovoltaic power system, or some other source of independent power.

[0098] As explained above, the power supply 540 can send power to one or more AC/DC converters 545. In some cases, the AC/DC converter 545 receives AC power from the power supply 540 and converts the AC power to DC power. The AC/DC converter 545 sends the raw DC power to one or more of the motors 590. When the motors 590 receive the DC power, the motors 590 rotate, under control of the controller 504, to generate mechanical energy in the mechanical energy transfer device 596. When the mechanical device 542 receives the mechanical energy from the mechanical energy transfer device 596, the mechanical device 542 operates. In some cases, a DC/AC inverter, an AC/AC converter, and/or the DC/DC converter 549 can be used to provide the correct type and level of power to the motors 590 in the event that the motors 590 use some other type and/or level of power than what is provided by the AC/DC converter 545.

[0099] The one or more AC/DC converters 545, the one or more DC/DC converters 549, and/or any other type of power transfer devices can be located in the cavity 501 (or in some other cavity, such as cavity 548) of the housing 503 or in some other housing (e.g., housing 392 of a motor 390). For example, an AC/DC converter 545 can be disposed in the housing (e.g., housing 392) of each motor 590. In certain example embodiments, each AC/DC converter 545, each DC/DC converter 549, and/or each other power transfer device of the VFD and motor assembly 502 can be individually replaceable (modular) without having to replace the entire VFD and motor assembly 502. In addition, or in the alternative, one or more AC/DC converters 545, one or more of the DC/DC converters 549, and/or one or more of any other power transfer device can be stand-alone devices. An AC/DC converter 545, a DC/DC converter 549, and/or other power transfer device can have one or more output channels, where each output channel is coupled to a motor 590 to provide power to the motor 590. Similarly, an AC/DC converter 545, a DC/DC converters 549, and/or any other power transfer device can have one or more input channels, where each input channel is coupled to one or more sources of power (e.g., power supply 540) to receive power from such one or more sources of power.

[00100] In some cases, one or more switches 570 can be used to determine which motor 190 is coupled to the power supply 540 and/or an AC/DC converter 545 at any particular point in time. A switch 570 has an open state and a closed state (position). In the open state, the switch 570 creates an open circuit, which prevents a motor 190 from receiving power from the power supply 540. In the closed state, the switch 570 creates a closed circuit, which allows a motor 190 to receive power from the power supply 540. In

certain example embodiments, the position of each switch 570 is controlled by the control engine 506 of the controller 504.

[00101] Each switch 570 can be any type of device that changes state or position (e.g., opens, closes) based on certain conditions. Examples of a switch 570 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 570 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 504.

[00102] In certain example embodiments, the one or more temperature control devices 572 control the temperature of the VFD and motor assembly 502 or portions thereof. A temperature control device 572 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 572 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 572 (or portions thereof) can be controlled by the control engine 506 of the controller 504.

[00103] In certain example embodiments, the one or more pressure regulating devices 574 control the pressure of the VFD and motor assembly 502 or portions thereof. A pressure regulating device 574 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 574 (or portions thereof) can be controlled by the control engine 506 of the controller 504.

[00104] As stated above, the VFD and motor assembly 502 can be placed in any of a number of environments. In such a case, the housing 503 of the VFD and motor assembly 502 (or components thereof) can be configured to comply with applicable standards for any of a number of environments. For example, the VFD and motor assembly 502 (or portions thereof) can be rated under applicable standards for marine and/or subsea environments.

[00105] Figure 6 illustrates one embodiment of a computing device 618 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 618 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 618 be interpreted as having any dependency or requirement relating to any one or combination of components illustrated in the example computing device 618.

[00106] Computing device 618 includes one or more processors or processing units 614, one or more memory/storage components 615, one or more input/output (I/O) devices 616, and a bus 617 that allows the various components and devices to communicate with one another. Bus 617 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 617 includes wired and/or wireless buses.

[00107] Memory/storage component 615 represents one or more computer storage media. Memory/storage component 615 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 615 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).

[00108] One or more I/O devices 616 allow a customer, utility, or other user to enter commands and information to computing device 618, 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 network, a printer, and a network card.

[00109] 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”.

[00110] “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.

[00111] The computer device 618 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 618 includes at least the minimal processing, input, and/or output means necessary to practice one or more embodiments.

[00112] Further, those skilled in the art will appreciate that one or more elements of the aforementioned computer device 618 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 506) 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.

[00113] Example embodiments provide a number of benefits. For example, VFD and motor assemblies described herein have a smaller footprint, weigh less, and can be tested at the surface at pressures experienced in subsea conditions before deploying the assembly into service. The redundancy of the motors within the example assembly increases reliability, extends the useful life of the equipment, and reduces costs, power

requirements, and maintenance requirements. Since the controller and the motors, as well as any associated wiring, are all contained within a common housing, these components are protected from natural and man-made hazards. In addition, use of a VFD further increases the efficiency and effectiveness of the equipment and operation of the associated mechanical device.

[00114] Further, multiple motors within a VFD and motor assembly and/or multiple VFD and motor assemblies can be used simultaneously to serve one or more mechanical devices. In such a case, a motor can be isolated (idled) without disrupting service to the mechanical device. In any case, by using example embodiments, the failure of motor does not affect the delivery of mechanical energy to the mechanical device.

[00115] By regulating the temperature of the VFD and motor assembly (or portions thereof) while in service in a subsea environment, which is often very cold, the useful life and level of service of the VFD and motor assembly (or portions thereof) in example embodiments can be increased. Similarly, by regulating the pressure of the VFD and motor assembly (or portions thereof) while in service in a subsea environment, the useful life and level of service of the VFD and motor assembly (or portions thereof) in example embodiments can be increased.

[00116] A controller included with example embodiments can track the performance of various aspects of the motors and/or other components of the VFD and motor assembly. In such a case, the controller can perform a number of functions to improve the reliability and performance of the example VFD and motor assembly, including but not limited to forecasting when a component of an example VFD and motor assembly may fail, implementing procedures and protocols to optimize the performance of the VFD and motor assembly, and notifying a user when a failure of a component of the VFD and motor assembly has occurred.

[00117] 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. An electric assembly for use in a subsea field operation, comprising:
a housing comprising at least one wall that forms a first cavity and a second cavity,
wherein the housing is rated for subsea conditions;
at least one motor disposed within the first cavity; and
at least one controller disposed within the second cavity and coupled to the at least one motor, wherein the at least one controller controls the at least one motor,
wherein the first cavity and the second cavity are physically separated from each other within the housing.
2. The electric assembly of Claim 1, wherein the at least one controller comprises a variable frequency drive.
3. The electric assembly of Claim 1, wherein the at least one motor comprises a first motor and a second motor, wherein the first motor and the second motor share a common rotating shaft disposed therethrough, and wherein the first motor and the second motor are disposed next to each other within the first cavity.
4. The electric assembly of Claim 3, wherein the first motor and the second motor are independently controlled by the at least one controller.
5. The electric assembly of Claim 4, wherein the first motor operates while the second motor is idle, wherein the first motor drives a mechanical device coupled to the common rotating shaft.
6. The electric assembly of Claim 4, wherein the at least one controller comprises a first controller and a second controller, wherein the first controller controls the first motor, and wherein the second controller controls the second motor.
7. The electric assembly of Claim 6, further comprising:

a mechanical device coupled to the at least one wall of the housing, wherein the mechanical device is driven by the at least one motor.

8. The electric assembly of Claim 7, wherein the mechanical device comprises a subsea hydraulic pump.

9. The electric assembly 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 second cavity of the housing, and wherein the temperature regulation module, using the at least one controller, maintains the temperature within an acceptable range of temperature values within the second cavity of the housing.

10. The electric assembly of Claim 9, wherein the temperature regulation module comprises at least one heat exchanger.

11. The electric assembly 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 first cavity of the housing, and wherein the pressure regulation module, using the at least one controller, maintains the pressure within an acceptable range of pressure values within the first cavity of the housing.

12. The electric assembly of Claim 11, wherein the pressure regulation module comprises at least one pump disposed within the second cavity of the housing.

13. The electric assembly of Claim 1, wherein the at least one motor is an axial flux electric motor.

14. The electric assembly of Claim 1, further comprising:
a plurality of electrical conductors coupled to the at least one controller and the at least one motor, wherein the plurality of electrical conductors are disposed entirely within the housing.

15. The electric assembly of Claim 1, wherein the at least one controller is configured to receive power from a power source located outside the housing.

16. The electric assembly of Claim 15, wherein the power source comprises a battery system disposed adjacent to the housing.

17. A system comprising:
an electric assembly comprising:
a housing comprising at least one wall that forms a first cavity and a second cavity, wherein the housing is rated for subsea conditions;
at least one motor disposed within the first cavity;
a drive mechanism coupled to the at least one motor, wherein the drive mechanism is disposed, at least in part, within the first cavity; and
at least one controller disposed within the second cavity and coupled to the at least one motor, wherein the at least one controller controls the at least one motor; and
a mechanical device coupled to the drive mechanism, wherein the drive mechanism is propelled by the at least one motor and operates the mechanical device,
wherein the first cavity and the second cavity are physically separated from each other within the housing of the electric assembly.

18. The system of Claim 17, wherein the mechanical device comprises a subsea hydraulic pump, and wherein the drive mechanism comprises a shaft.

19. The system of Claim 17, further comprising:
a power supply coupled to the at least one controller, wherein the power supply provides raw power to the at least one controller, wherein the at least one controller uses the raw power to generate finished power, wherein the at least one controller sends the finished power to the at least one motor.

20. The system of Claim 17, further comprising:
at least one sensor coupled to the at least one controller, wherein the at least one controller uses measurements taken by the sensor to regulate at least one condition within the first cavity of the housing of the electric assembly.

1/8

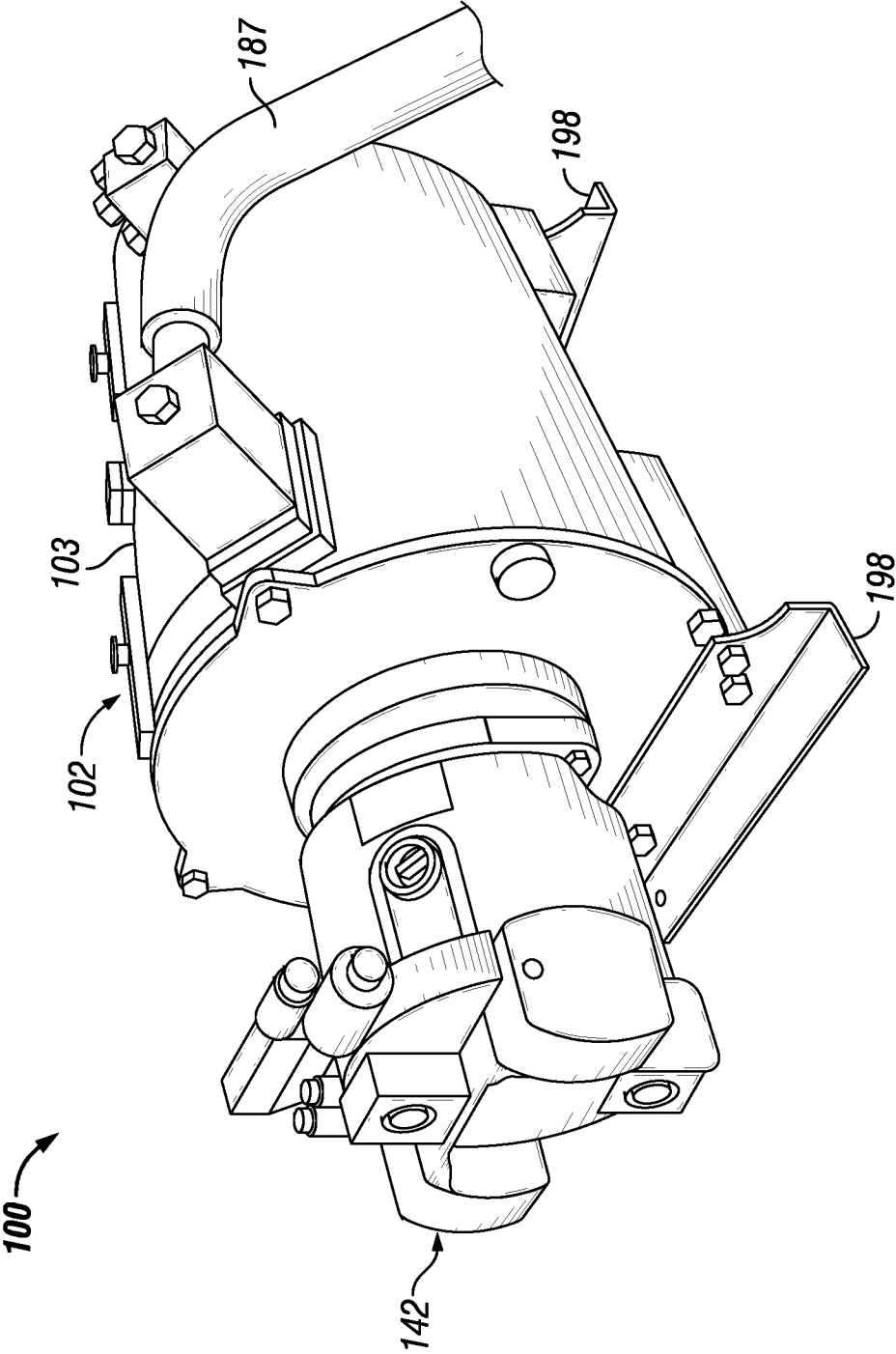


FIG. 1A

2/8

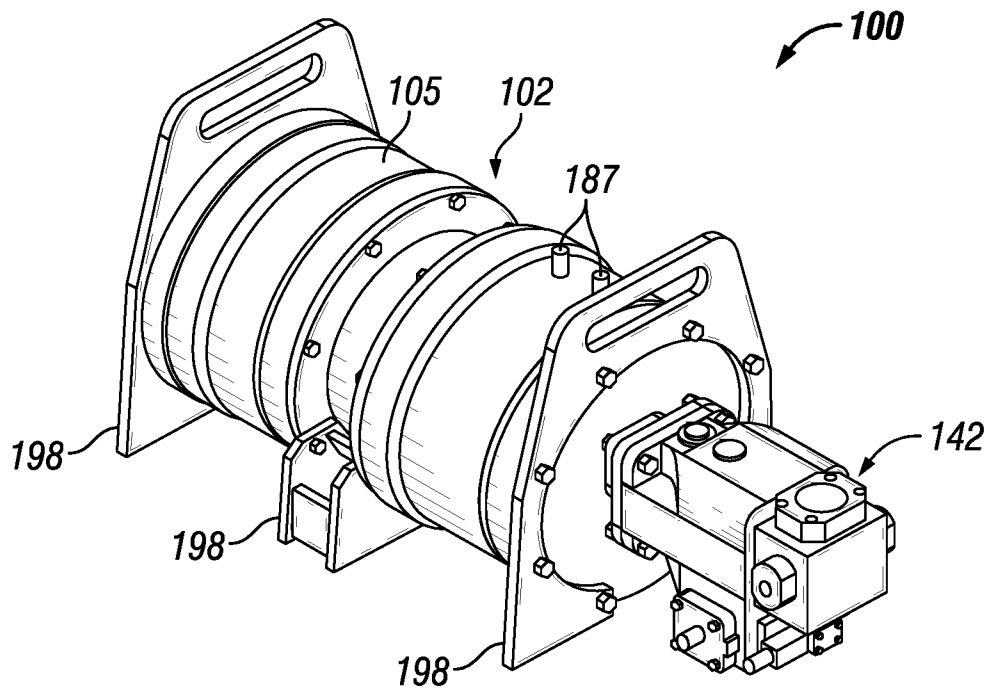


FIG. 1B

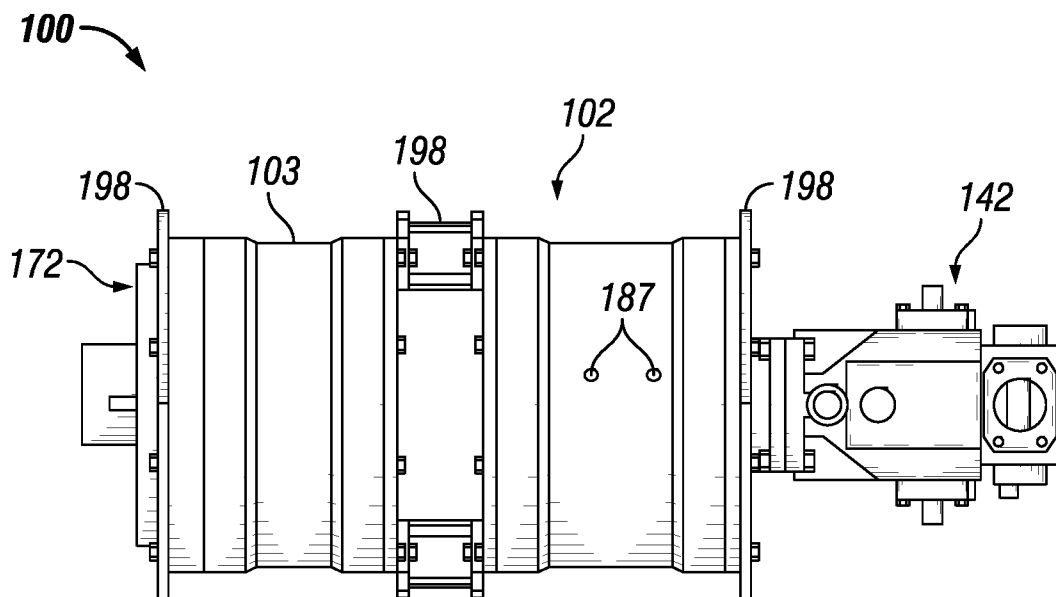


FIG. 1C

3/8

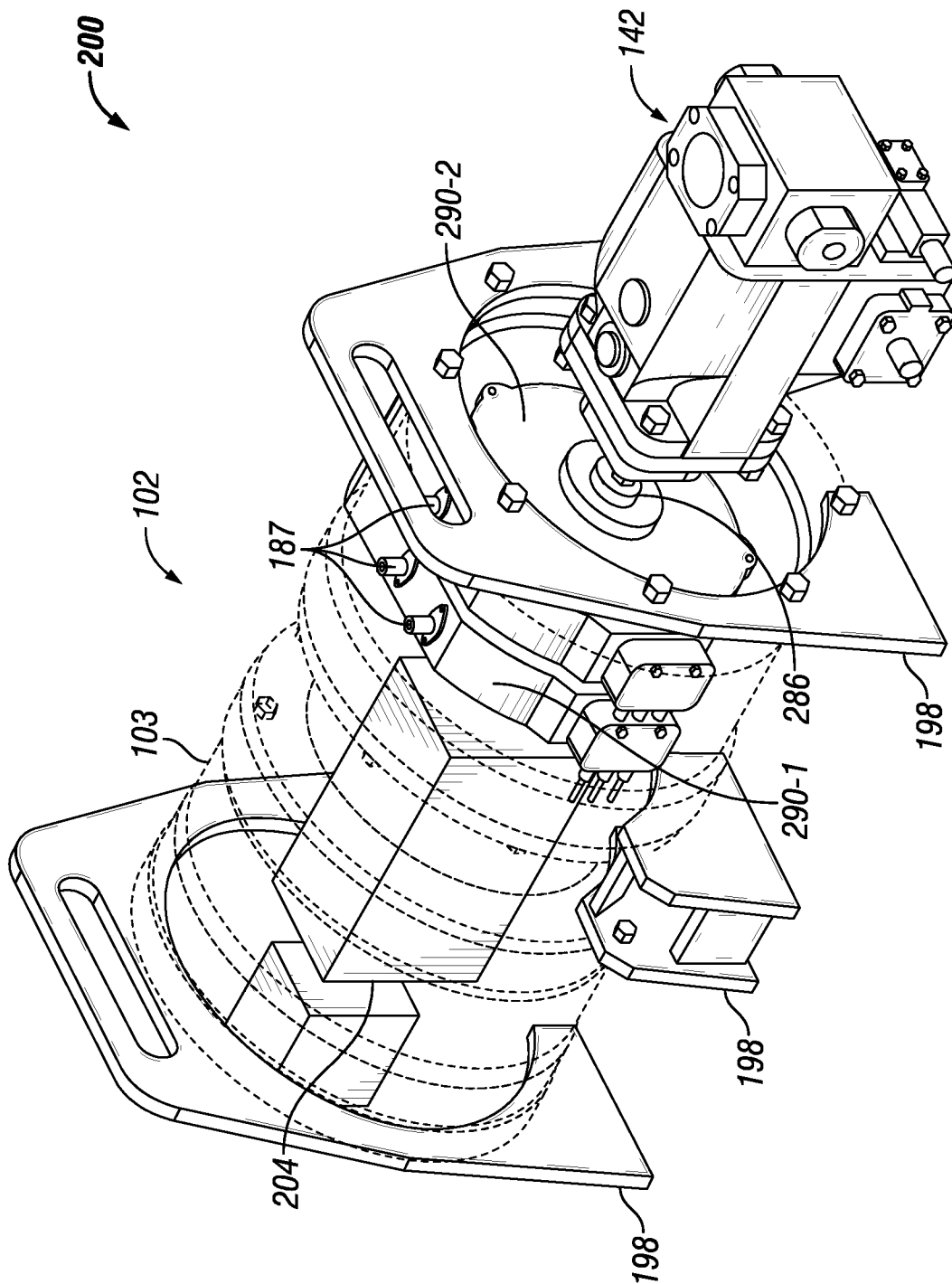


FIG. 2A

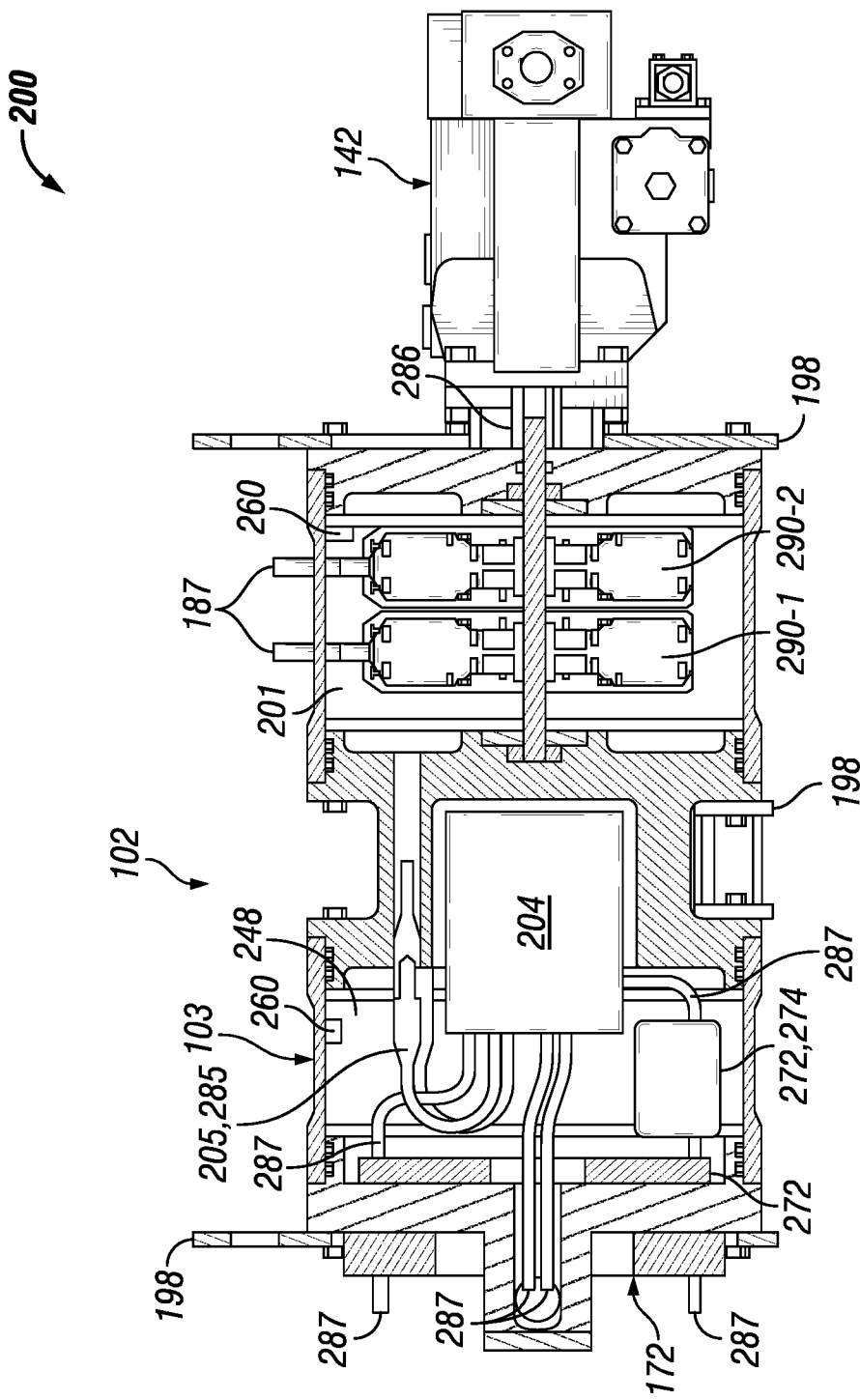
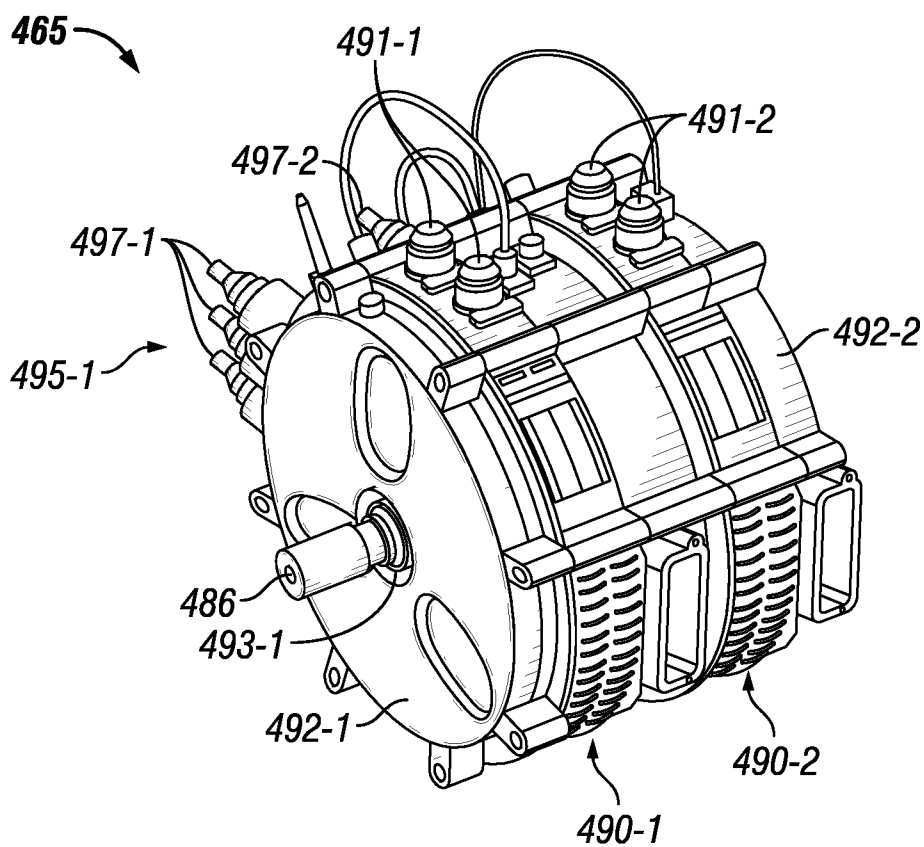
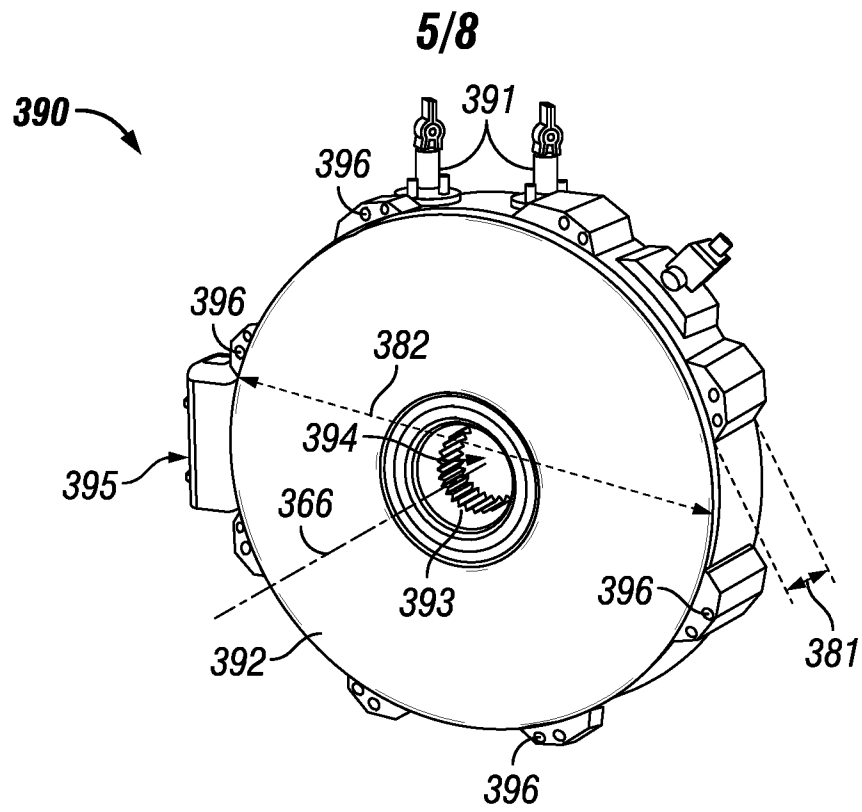


FIG. 2B



6/8

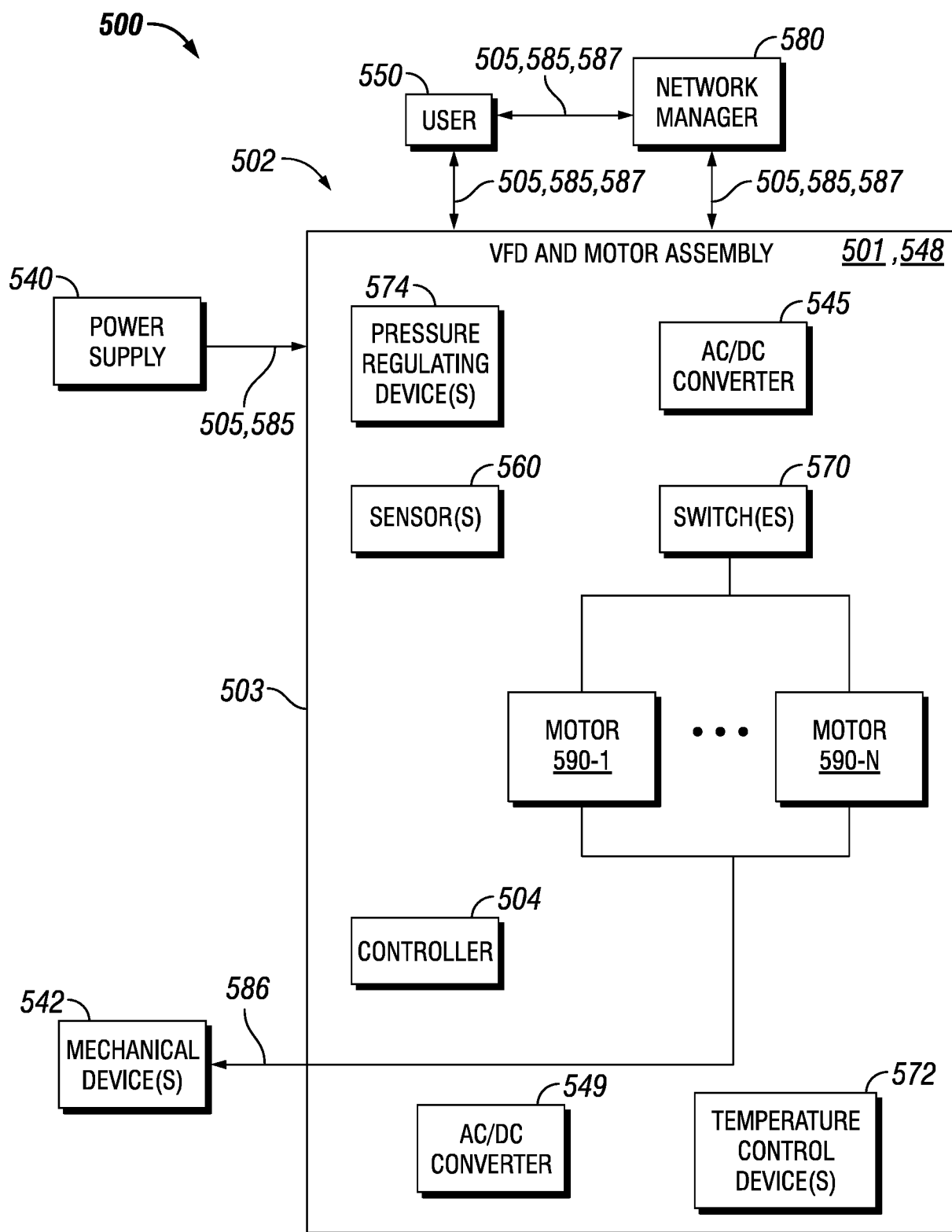


FIG. 5A

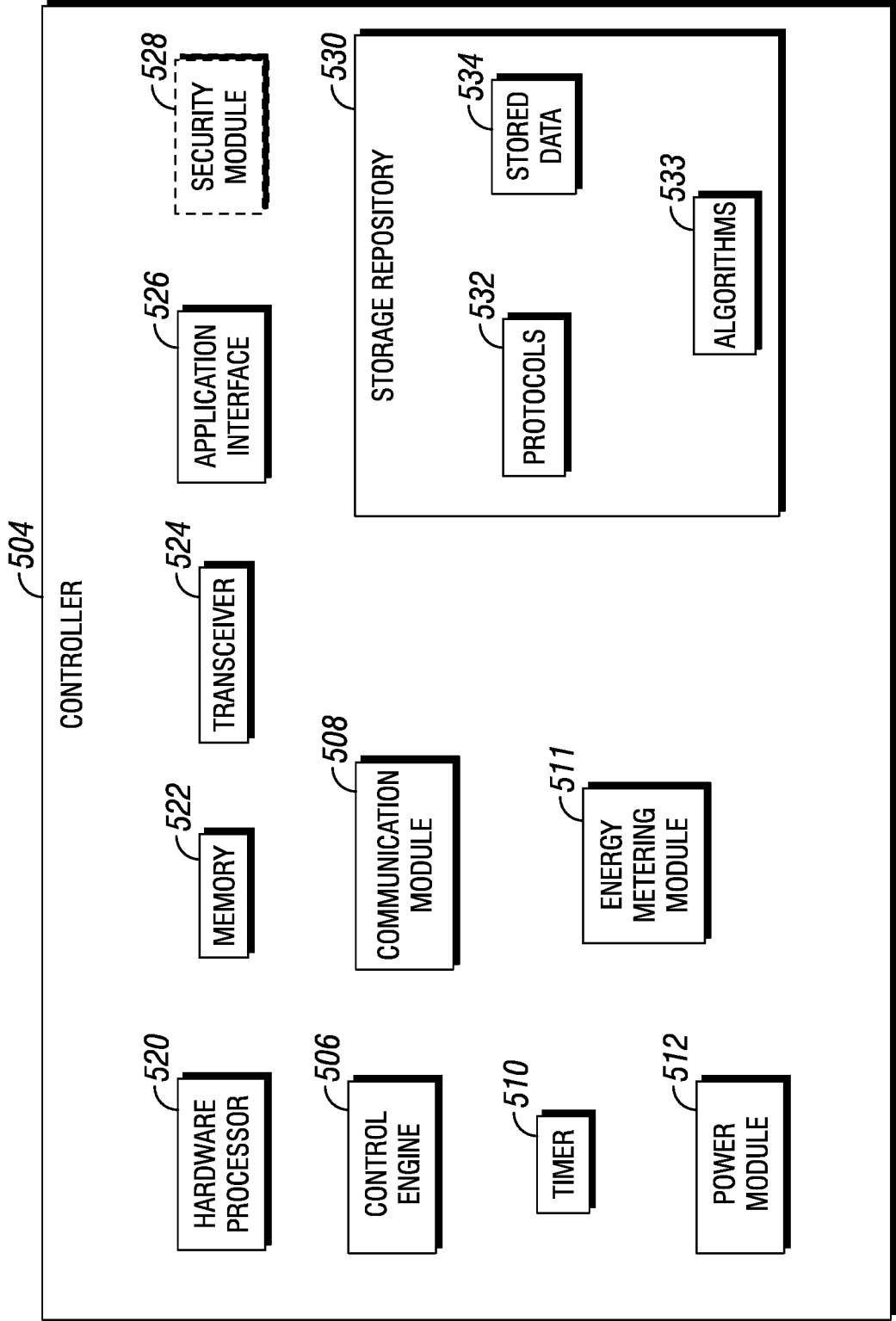
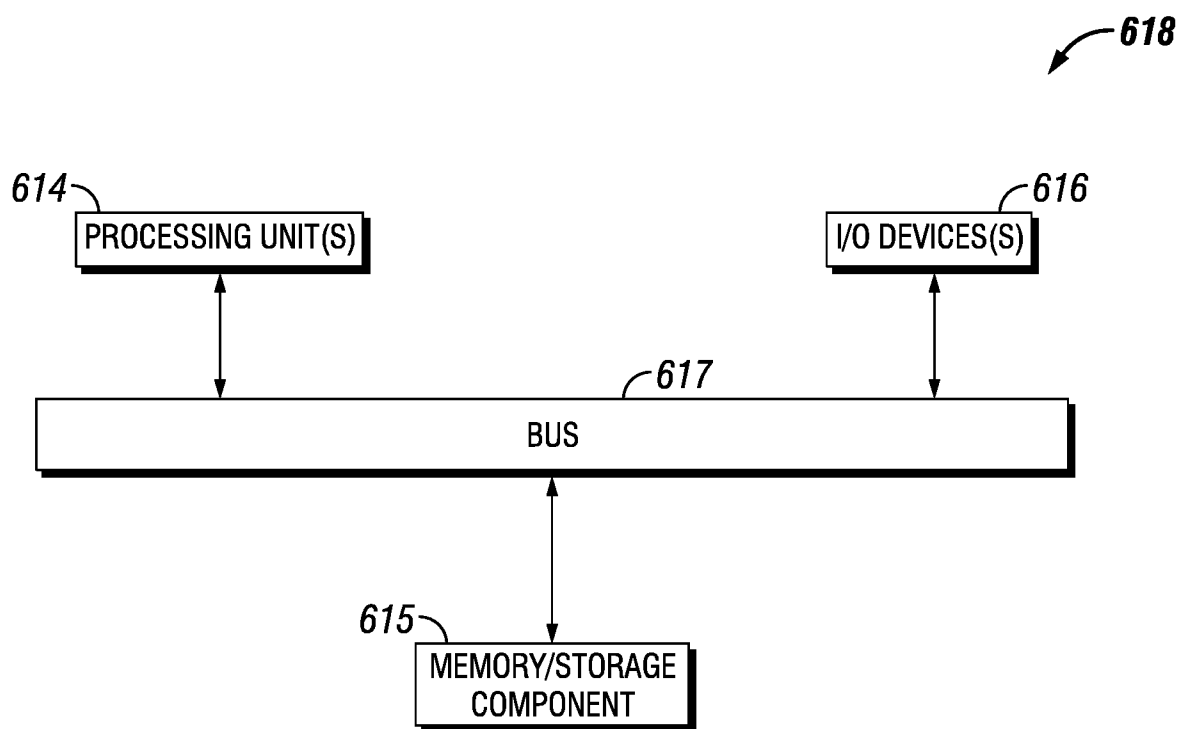


FIG. 5B

8/8**FIG. 6**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US17/56649

A. CLASSIFICATION OF SUBJECT MATTER

IPC - E21B 33/035, 43/01; F04D 13/00, 13/08; H02M 5/00, 5/451; H02P 27/04, 27/06 (2017.01)

CPC - E21B 33/0355; F04D 13/086, 25/0686; H02P 27/06

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

See Search History document

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 — Y	US 5,166,677 A (SCHOENBERG, R) 24 November 1992; Column 6, Lines 6-7; Column 6, Lines 9-11; Column 6, Lines 43-45	1, 14-15, 17, 19 2, 9-13, 16, 20
X	WO 2009/045110 A1 (MULTICONTROL HYDRAULICS AS) 9 April 2009; Page 1, Lines 3-5; Page 7, Lines 7-14; Page 7, Lines 20-21	1, 17, 18
Y	US 2011/0304289 A1 (BURDICK, J) 15 December 2011; Paragraphs [0016], [0017]	2
Y	US 2016/0024887 A1 (CAMERON INTERNATIONAL CORPORATION) 28 January 2016; Paragraphs [0003], [0022], [0025]	9-10, 20
Y	US 2013/0136634 A1 (SAELE, O) 30 May 2013; Paragraphs [0009], [0019], [0020], [0039], [0042], [0053]	11-12
Y	WO 2008/031883 A1 (WHITEHEAD ALENIA SISTEMI SUBACQUEI) 20 March 2008; Page 2, Lines 5-8; Page 3, Lines 10-15	13
Y	US 2013/0292130 A1 (EAGLEPICHER TECHNOLOGIES, LLC et al.) 7 November 2013; Paragraphs [0006], [0042], [0047]	15-16
A	US 8,810,427 R2 (IRFRAL, C et al.) 19 August 2014; Column 3, Lines 5-8	3-8
A	US 2014/0205475 A1 (DALE, H) 24 July 2014; Paragraph [0004]	3-8



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"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

29 November 2017 (29.11.2017)

Date of mailing of the international search report

28 DEC 2017

Name and mailing address of the ISA/

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

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Shane Thomas

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US17/56649

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/0294939 A1 (GILARRANZ, J et al.) 7 November 2013; Paragraph [0014]	3-8