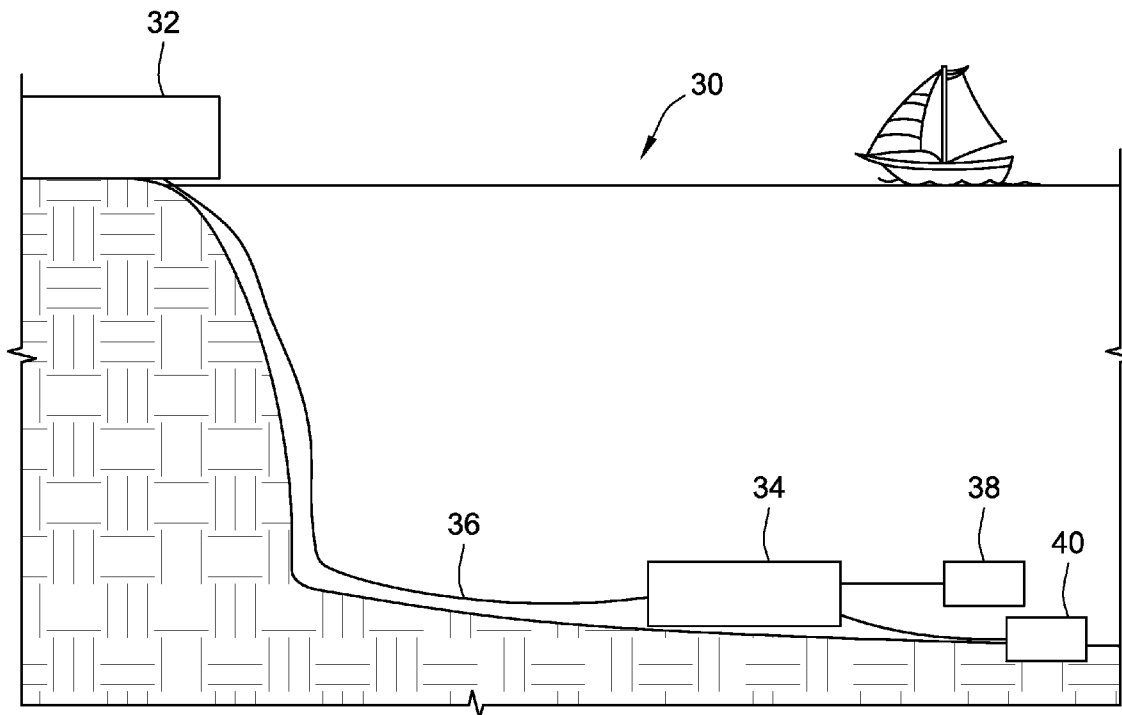




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(19) **United States**(12) **Patent Application Publication**
Hazel et al.(10) **Pub. No.: US 2013/0286546 A1**(43) **Pub. Date: Oct. 31, 2013**(54) **SUBSEA ELECTRICAL DISTRIBUTION
SYSTEM HAVING A MODULAR SUBSEA
CIRCUIT BREAKER AND METHOD FOR
ASSEMBLING SAME****Publication Classification**(51) **Int. Cl.**
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USPC **361/602; 29/825**(71) Applicant: **SCHNEIDER ELECTRIC
INDUSTRIES SAS**, Rueil-Malmaison
(FR)(72) Inventors: **Terence George Hazel**, Fontaine (FR);
Pierrick Andrea, Seyssinet-Pariset (FR)(73) Assignee: **SCHNEIDER ELECTRIC
INDUSTRIES SAS**, Rueil-Malmaison
(FR)(21) Appl. No.: **13/706,141**(22) Filed: **Dec. 5, 2012****Related U.S. Application Data**(60) Provisional application No. 61/639,865, filed on Apr.
28, 2012.(57) **ABSTRACT**

A system and method for coupling electrical power subsea. The system comprises a subsea electrical distribution system having at least one subsea circuit breaker assembly. The subsea circuit breaker assembly comprises a modular subsea busbar assembly configured to receive a plurality of modular subsea circuit breaker assemblies and at least one modular subsea circuit breaker assembly secured to the modular subsea busbar assembly. The modular subsea circuit breaker assemblies may be coupled by subsea power cables to a source or power, an electrical load, or other subsea circuit breaker assemblies.



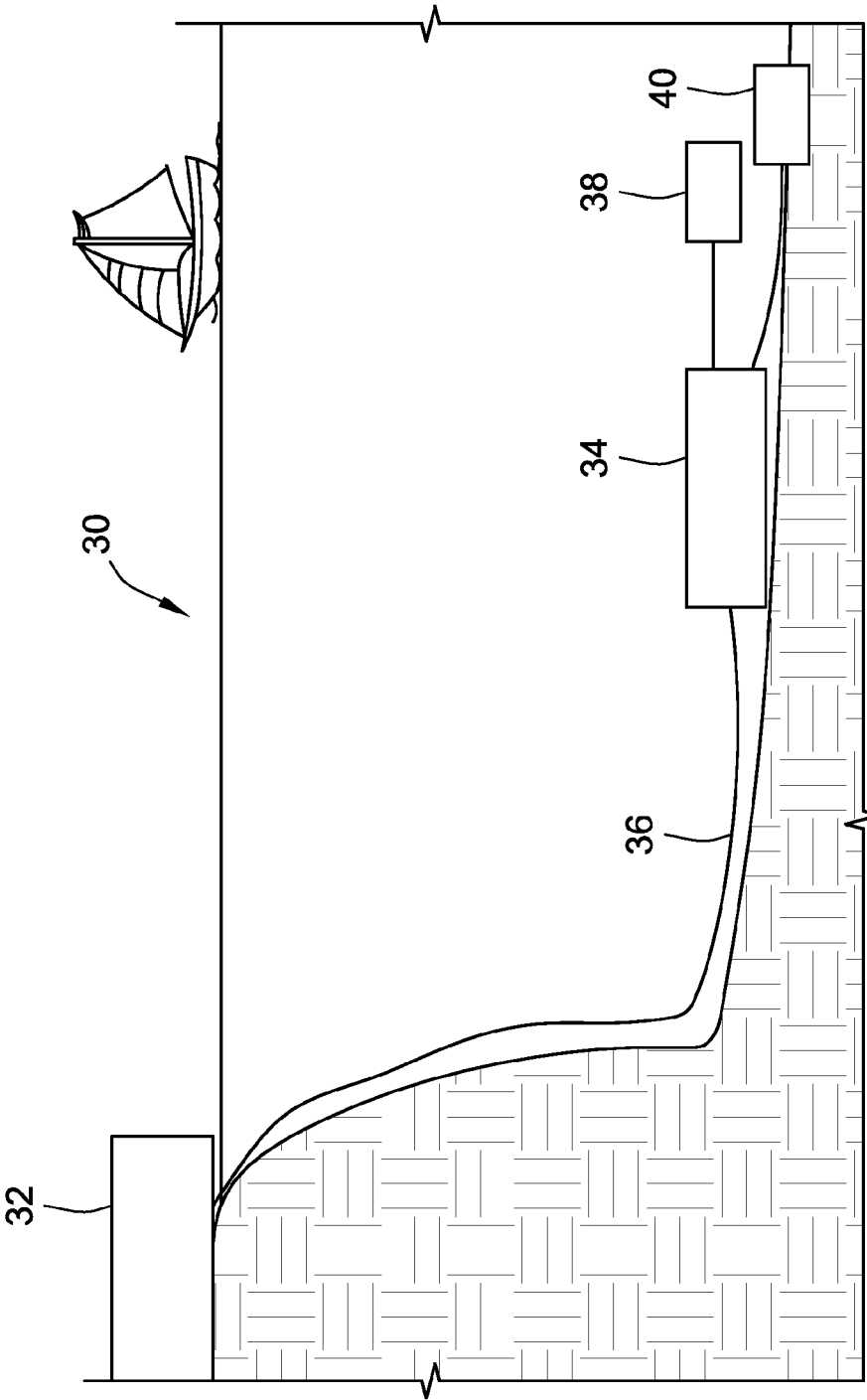
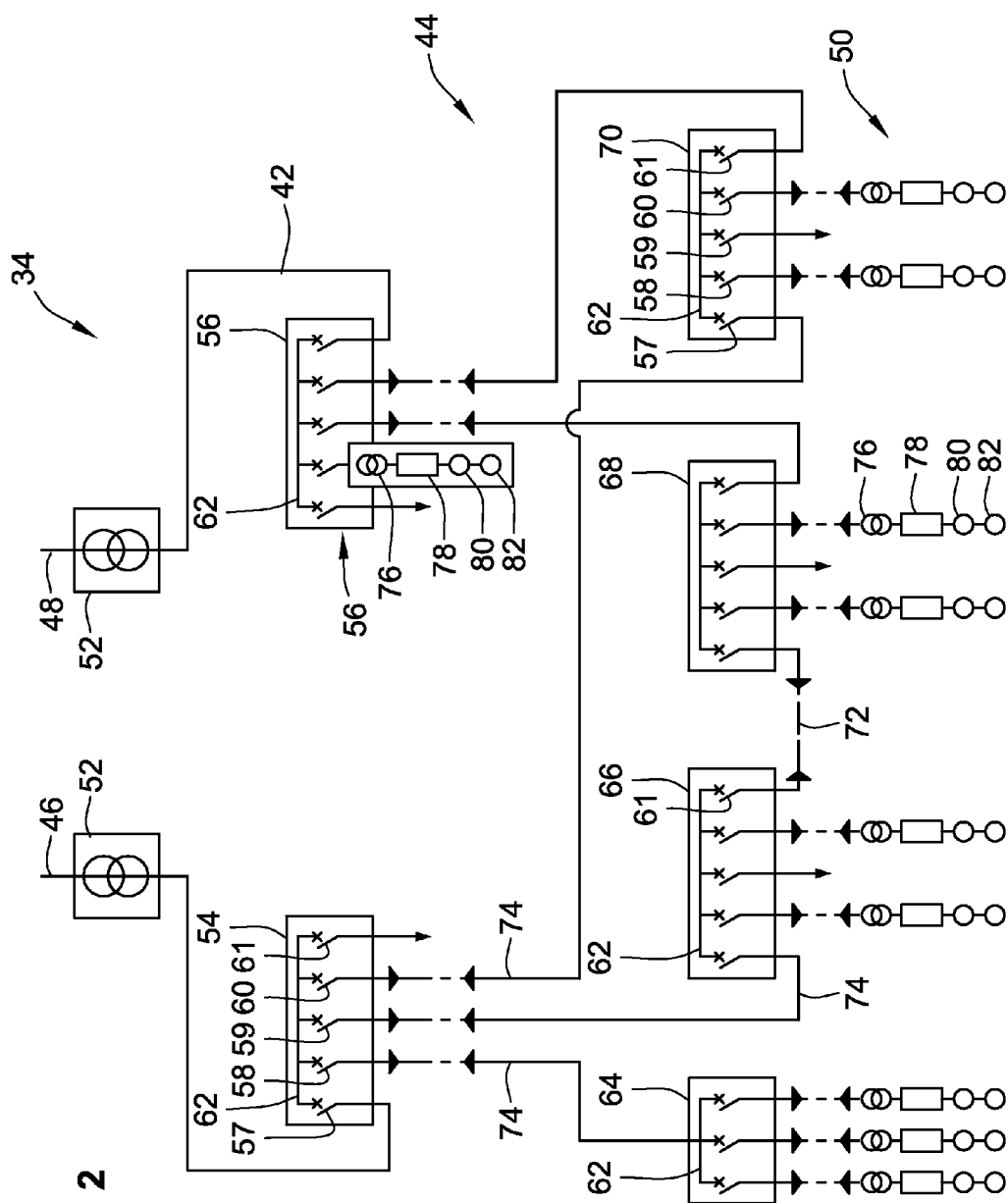


FIG. 1

FIG. 2



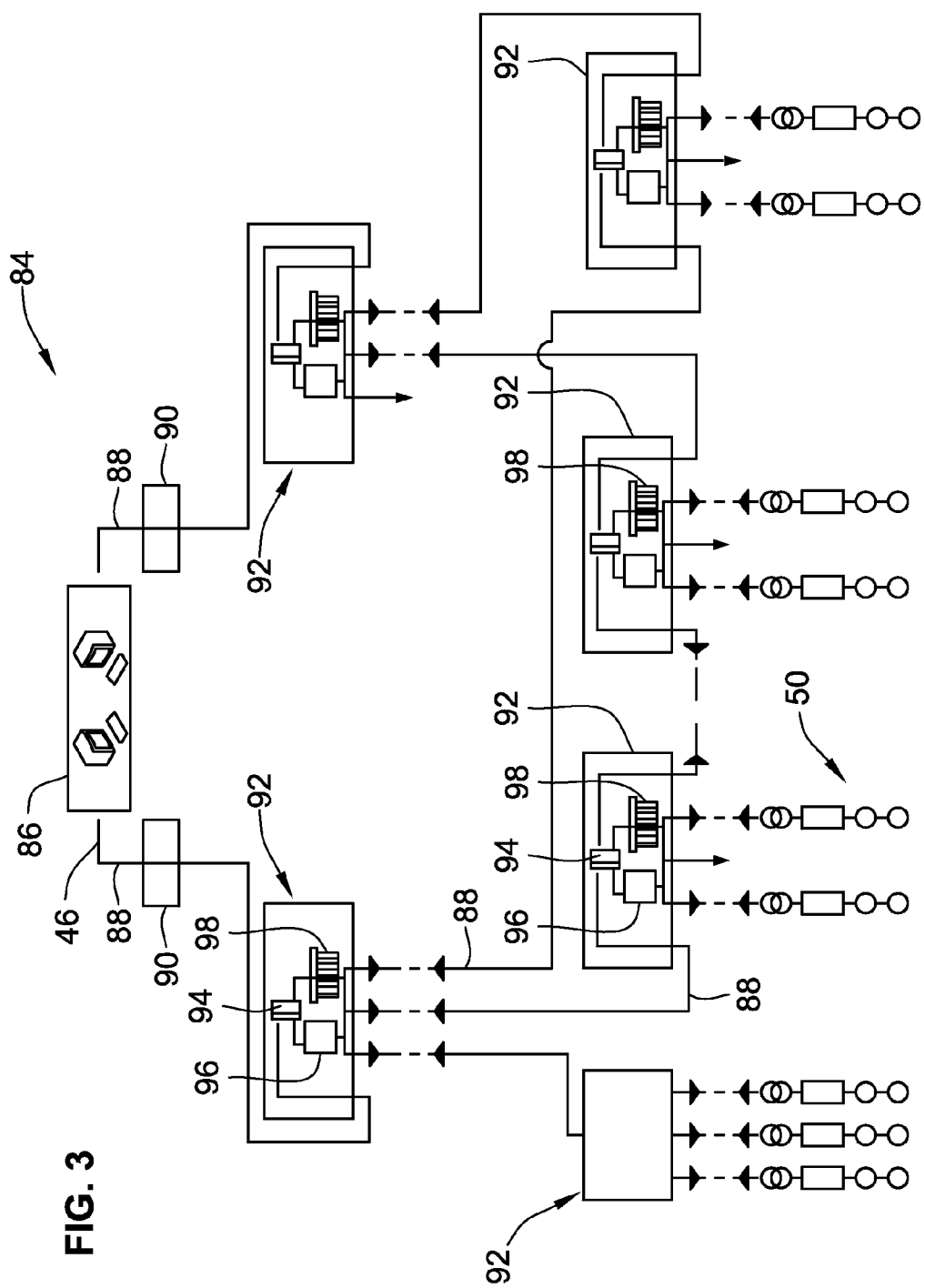


FIG. 3

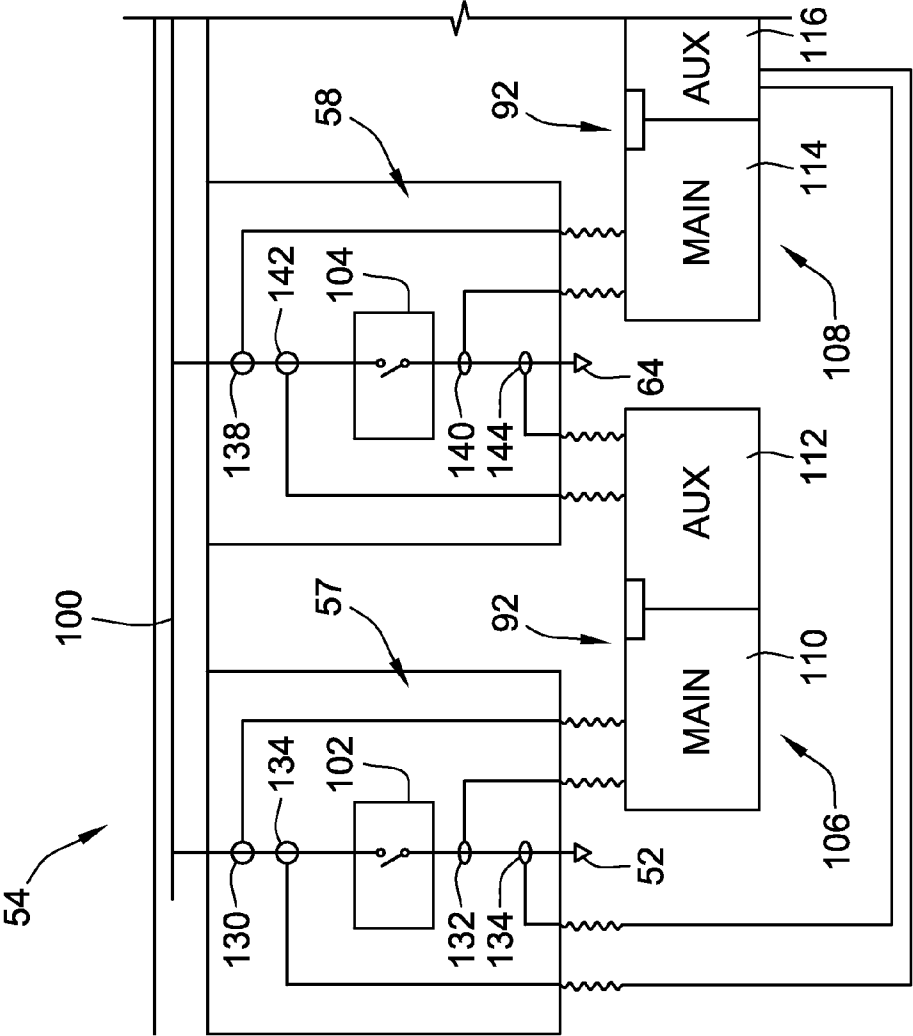


FIG. 4

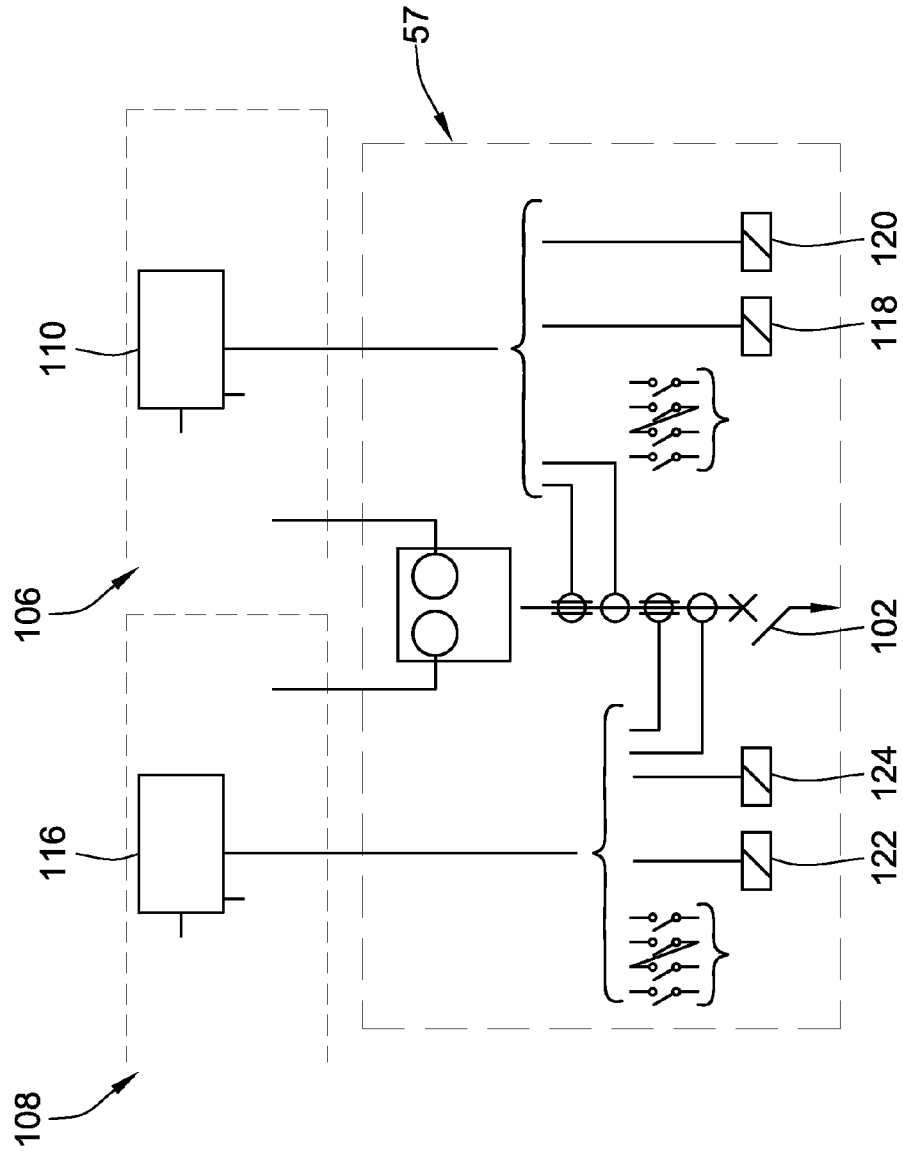


FIG. 5

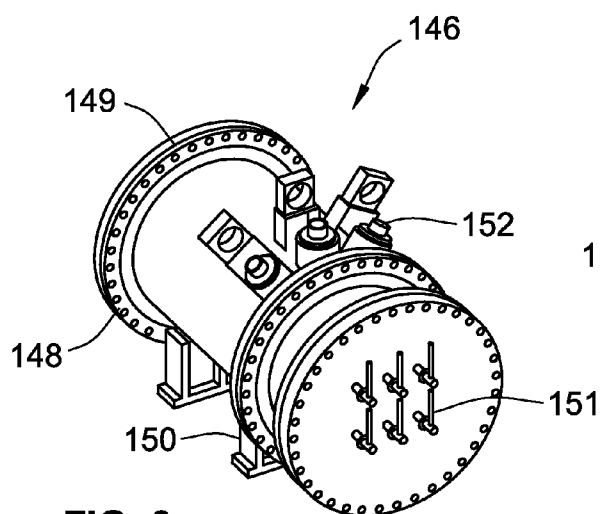


FIG. 6

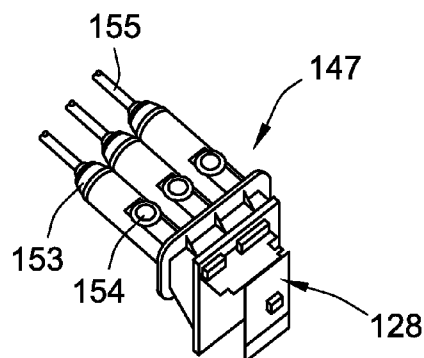


FIG. 7

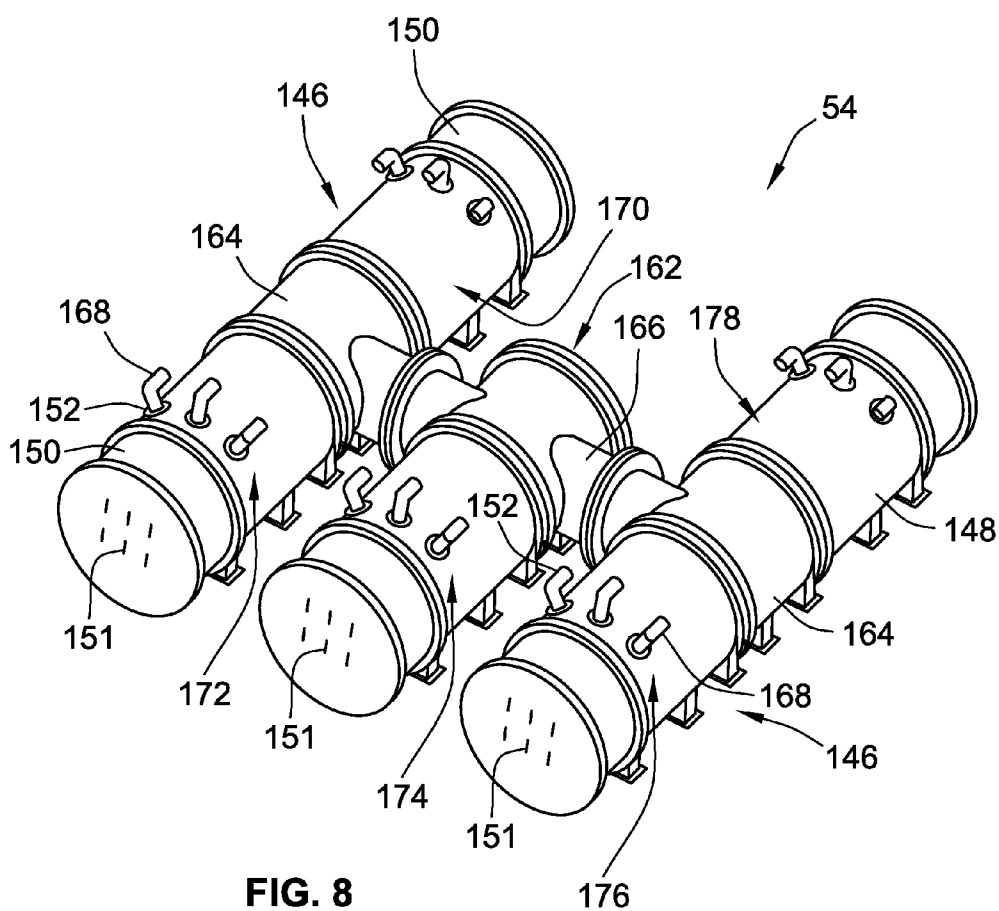


FIG. 8

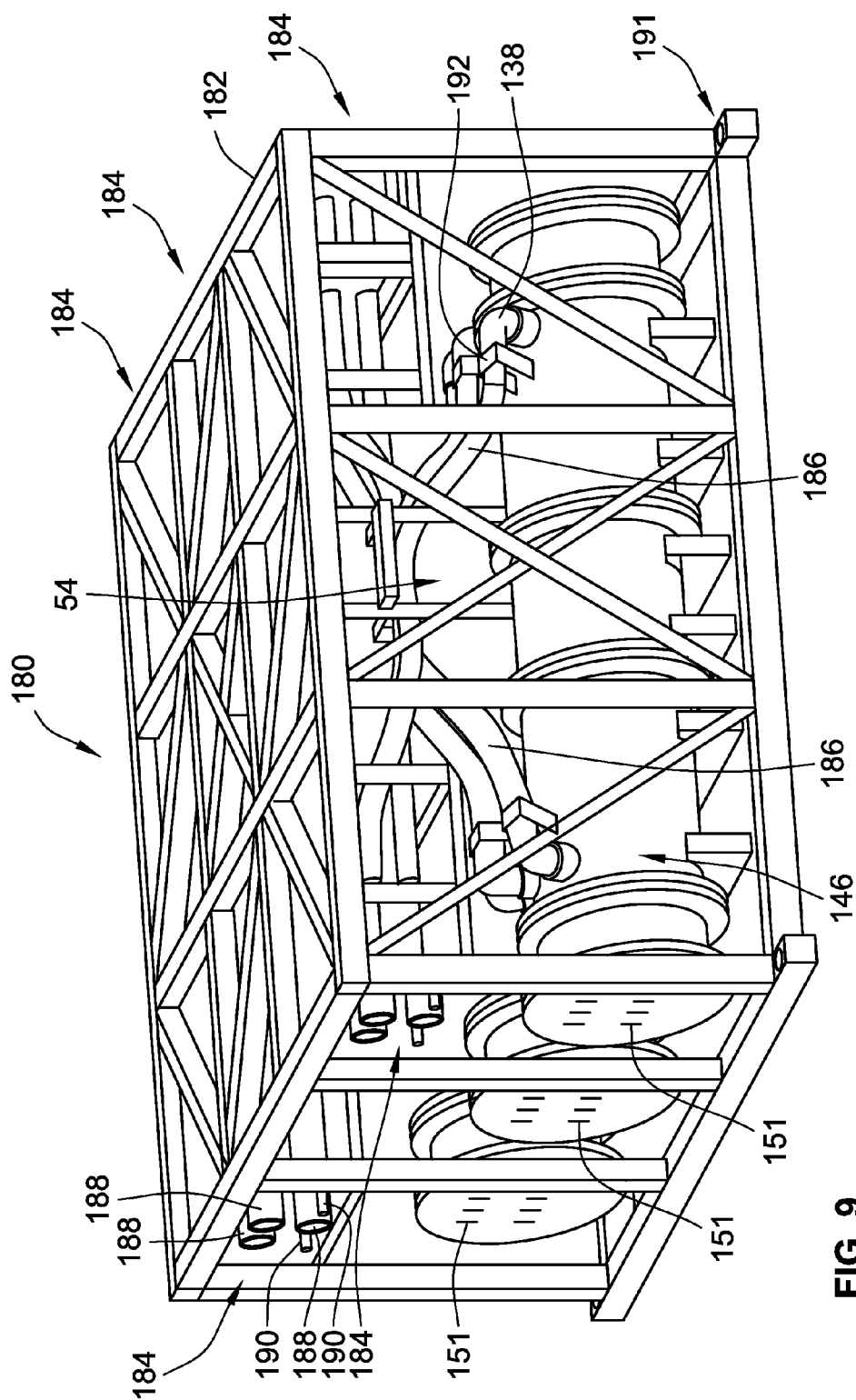


FIG. 9

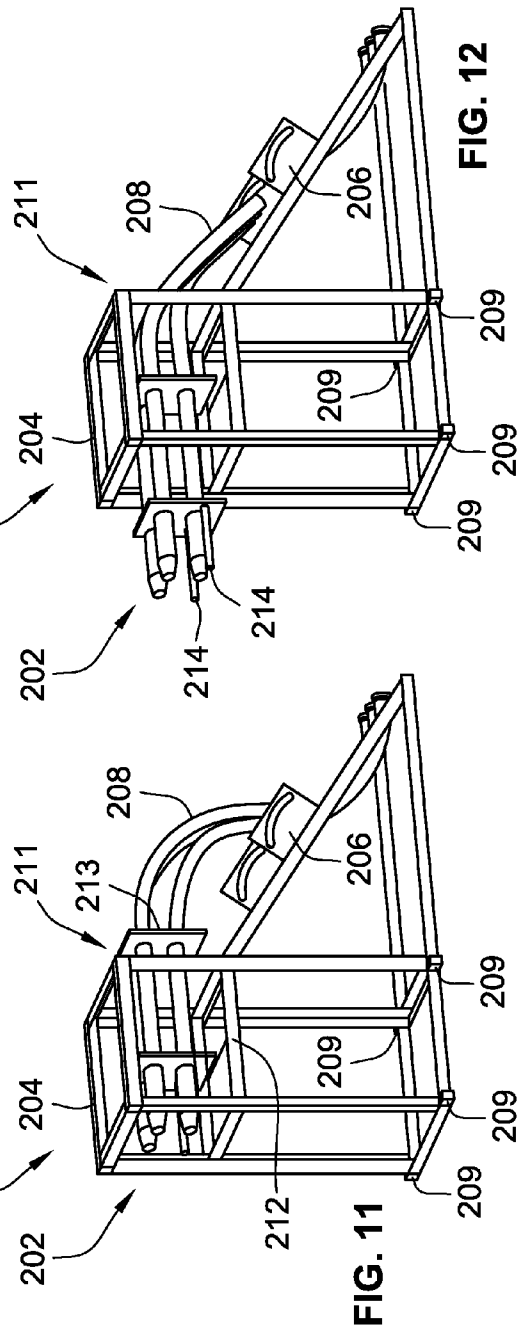
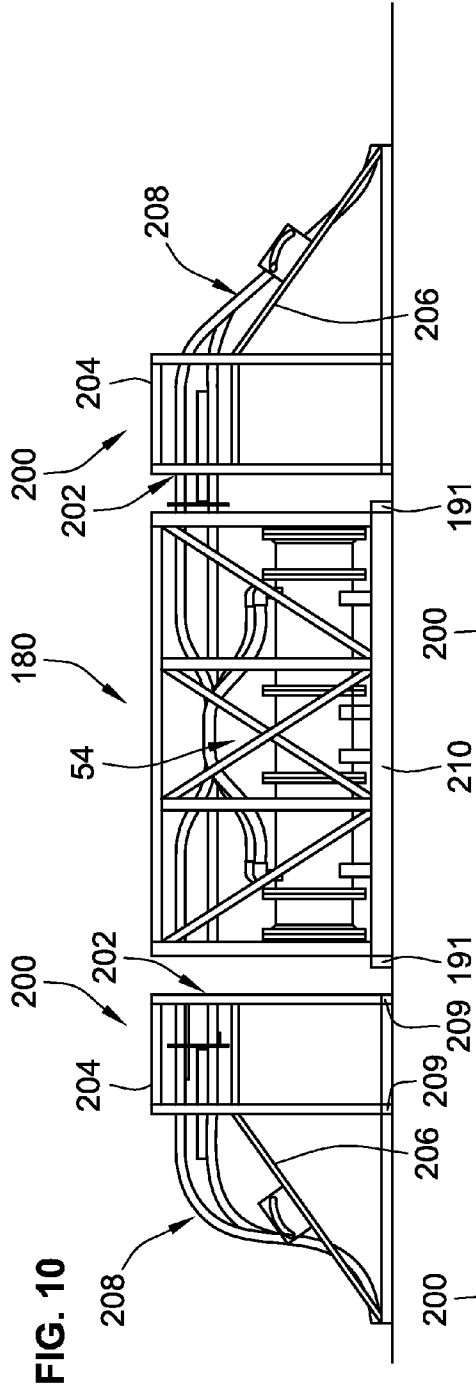
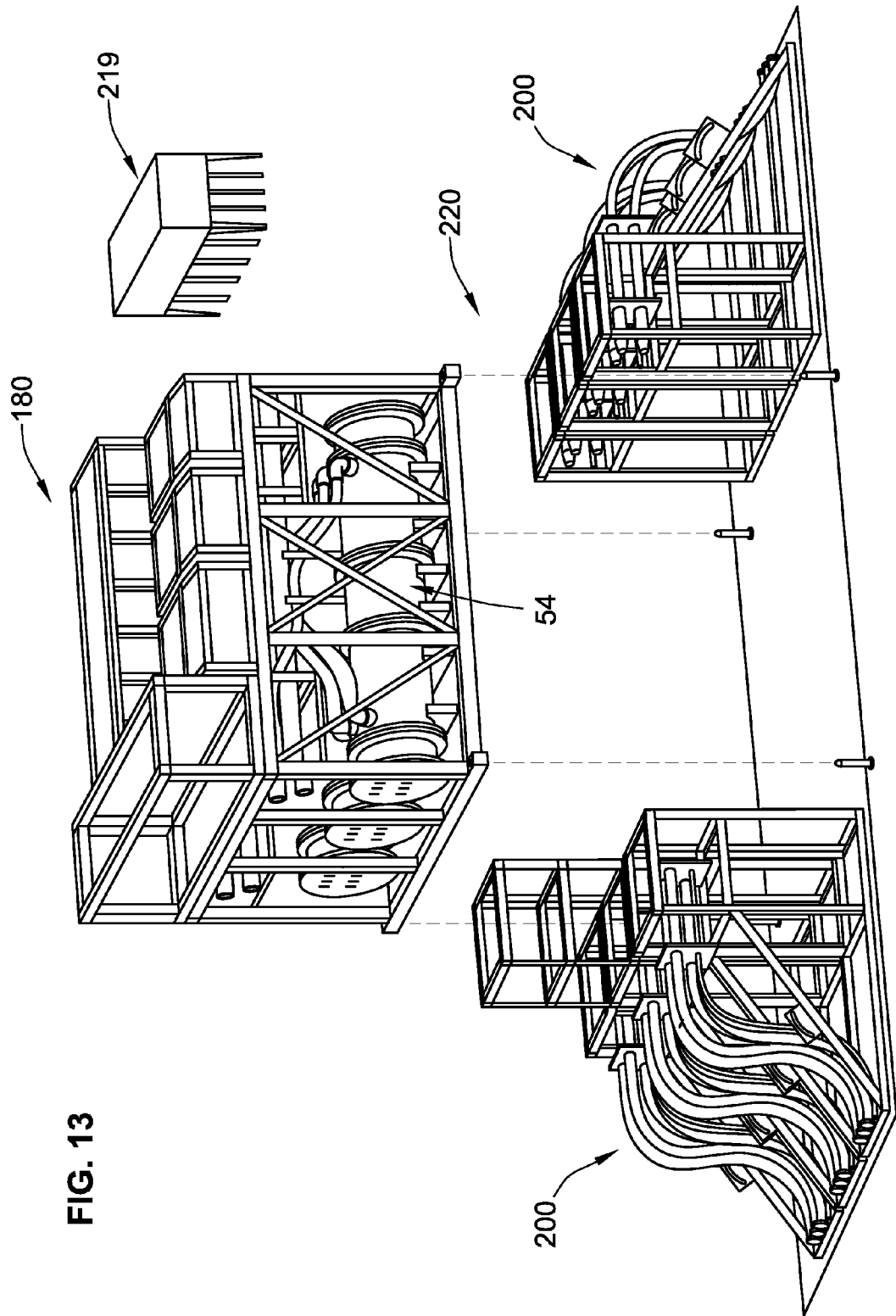


FIG. 12



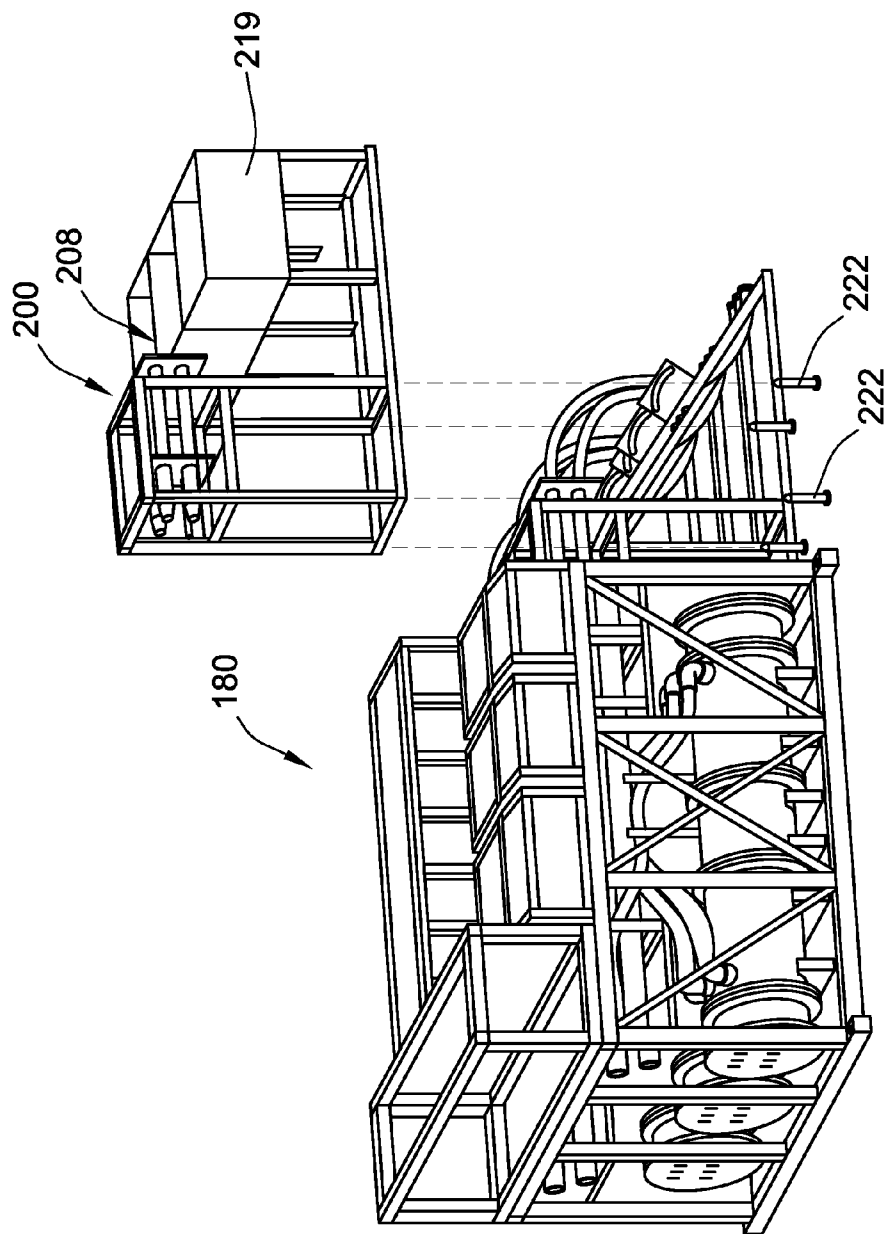


FIG. 14

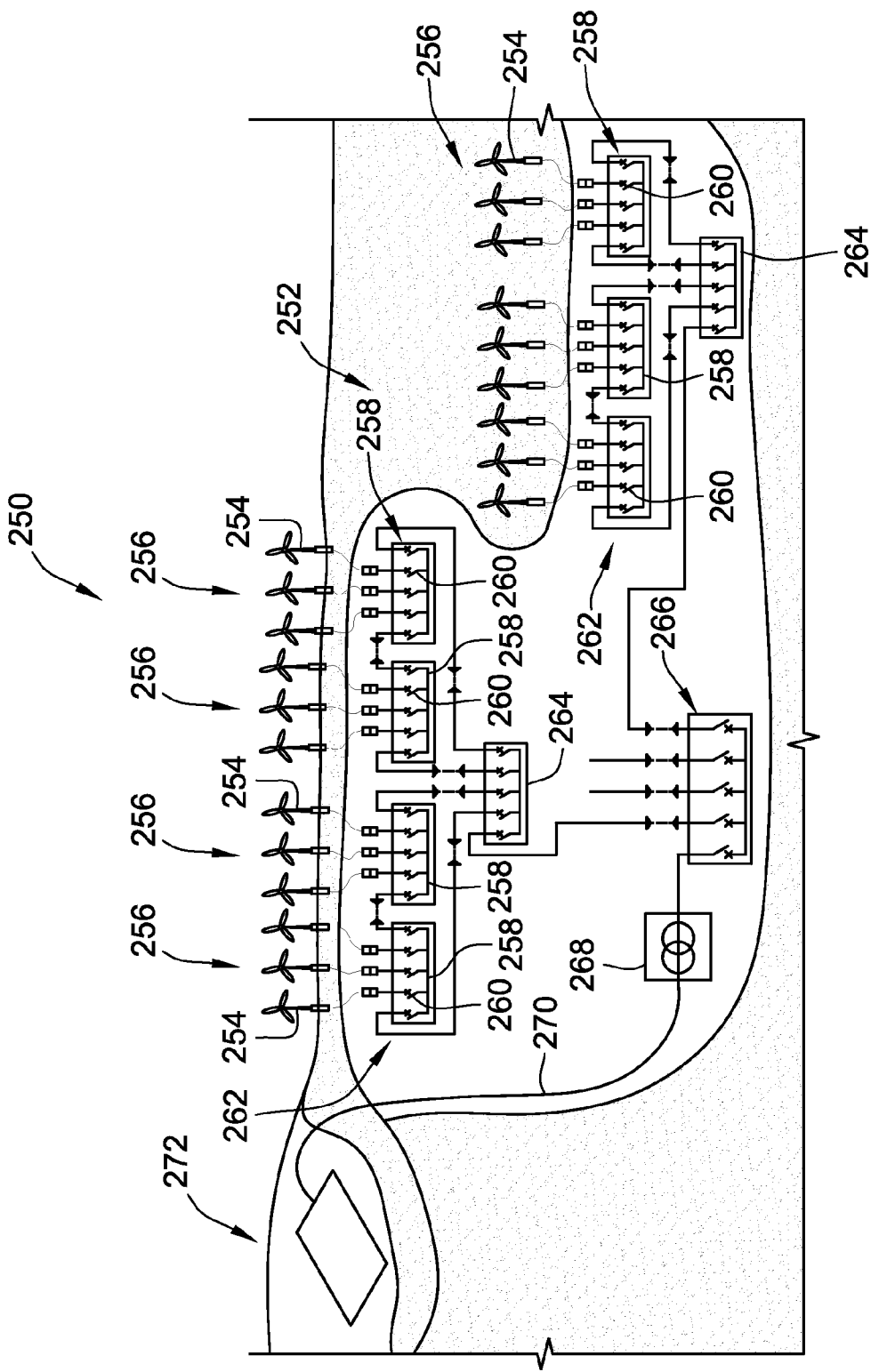


FIG. 15

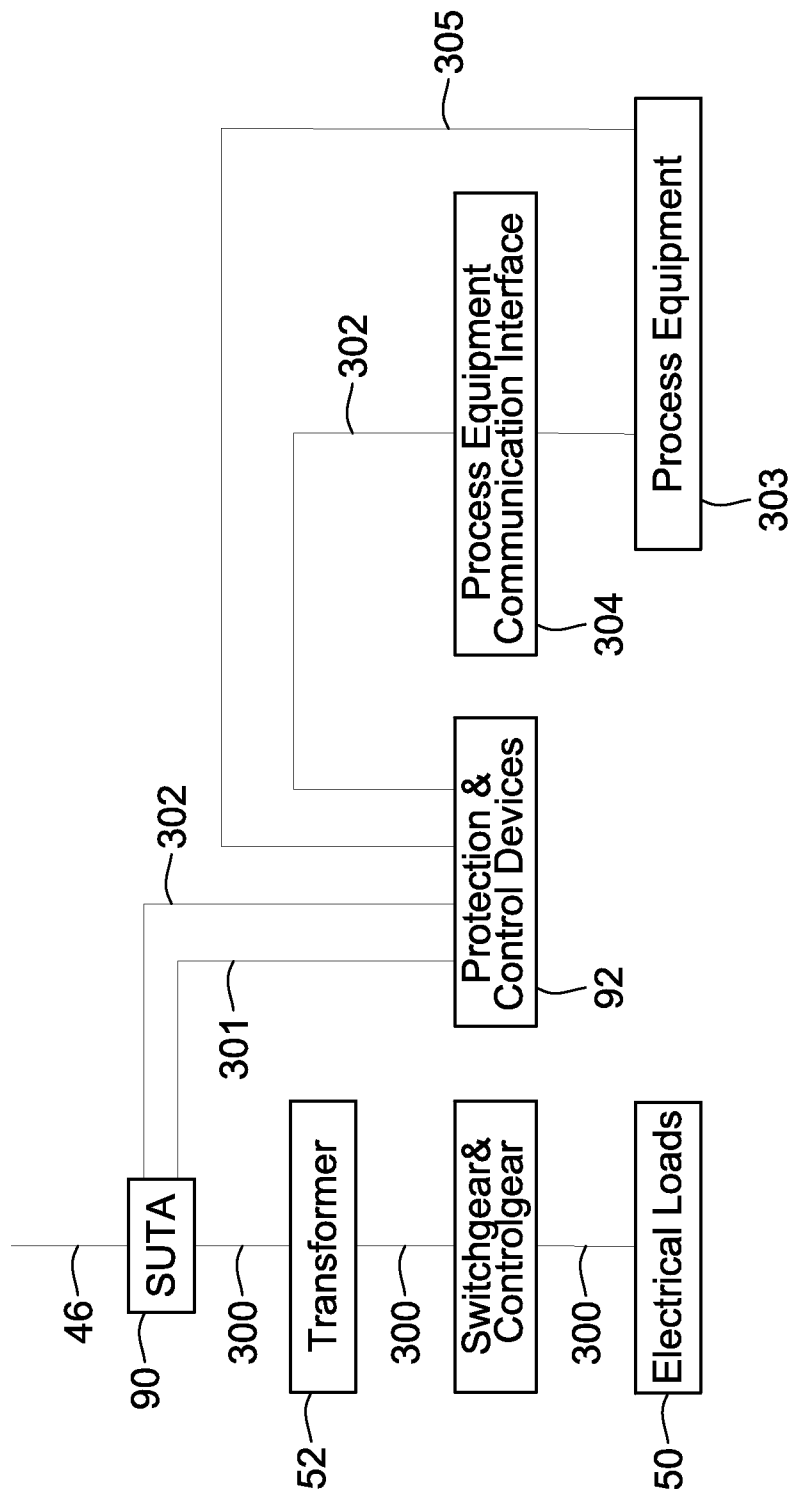


FIG. 16

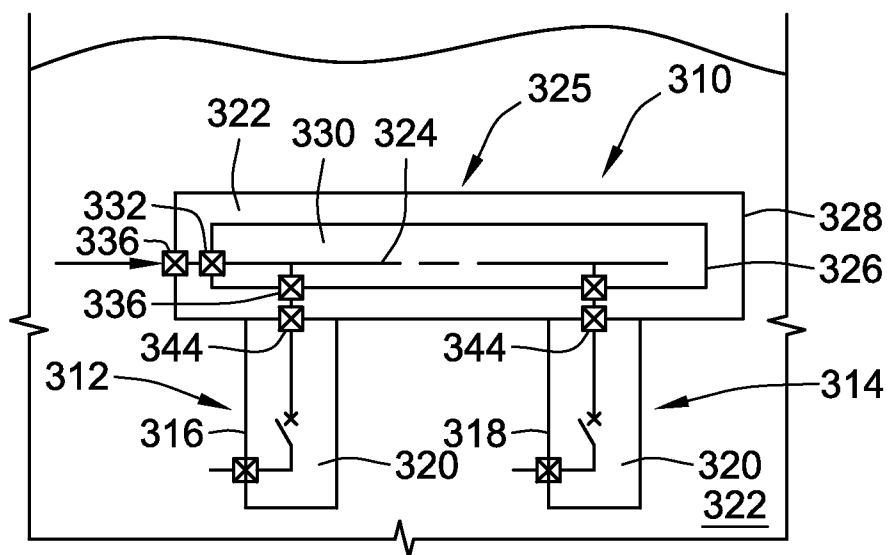


FIG. 17
(PRIOR ART)

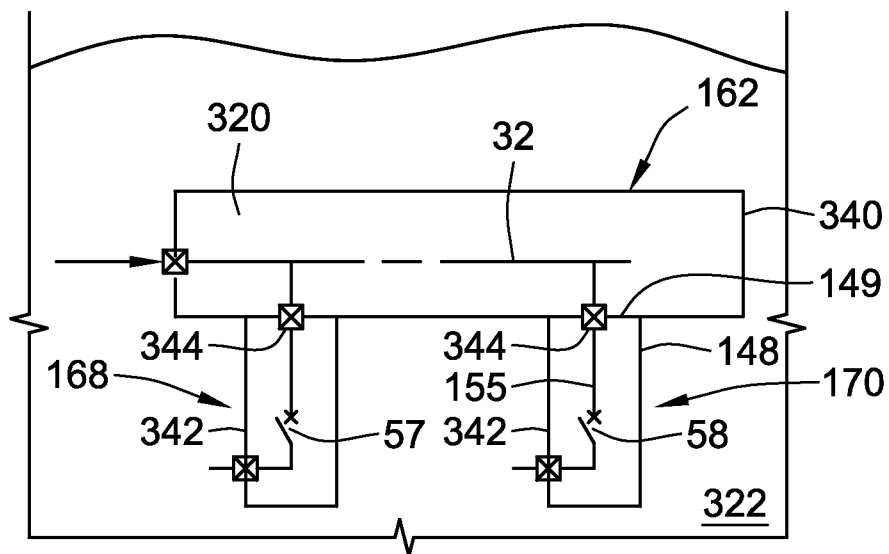


FIG. 18

FIG. 19

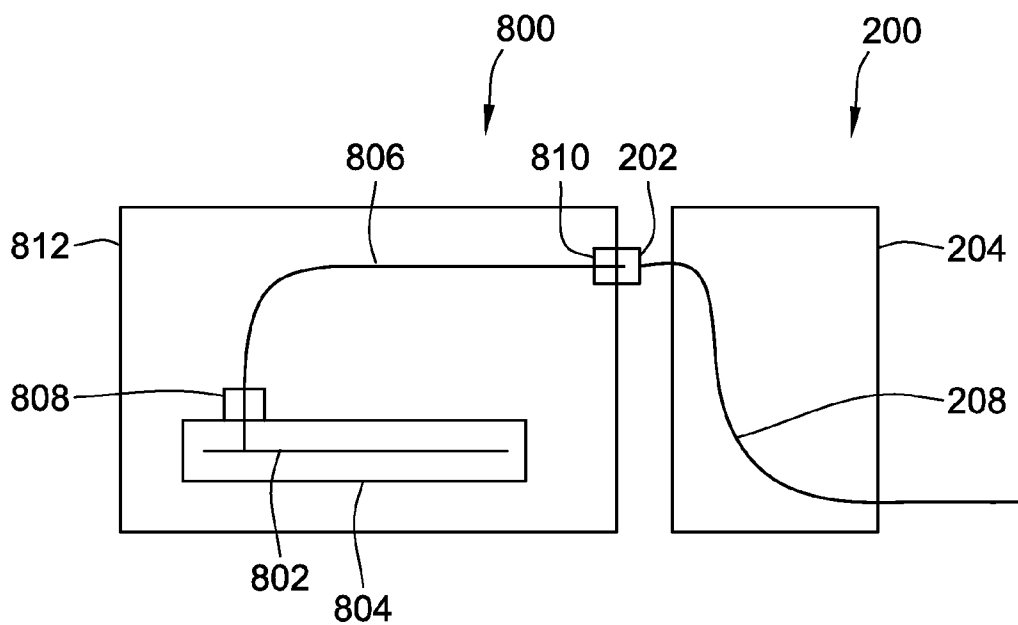
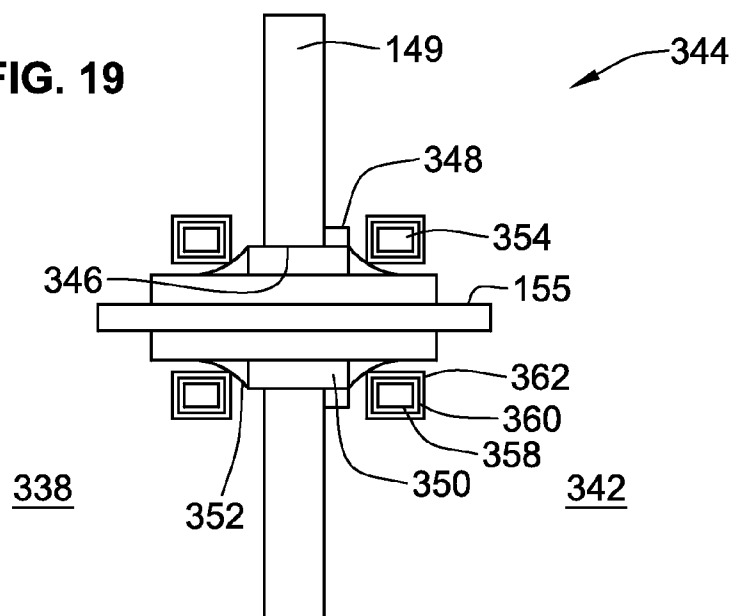


FIG. 22

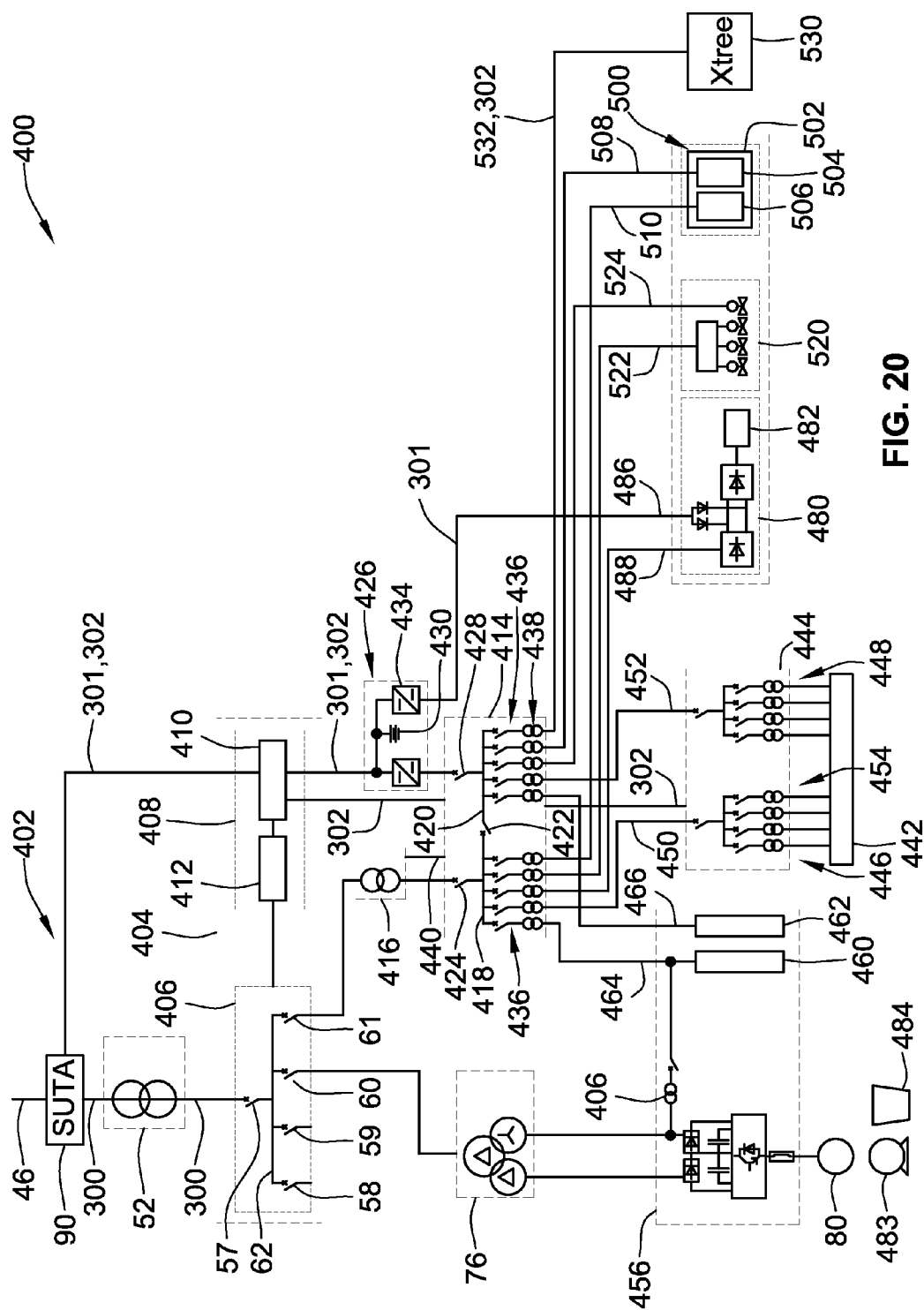


FIG. 20

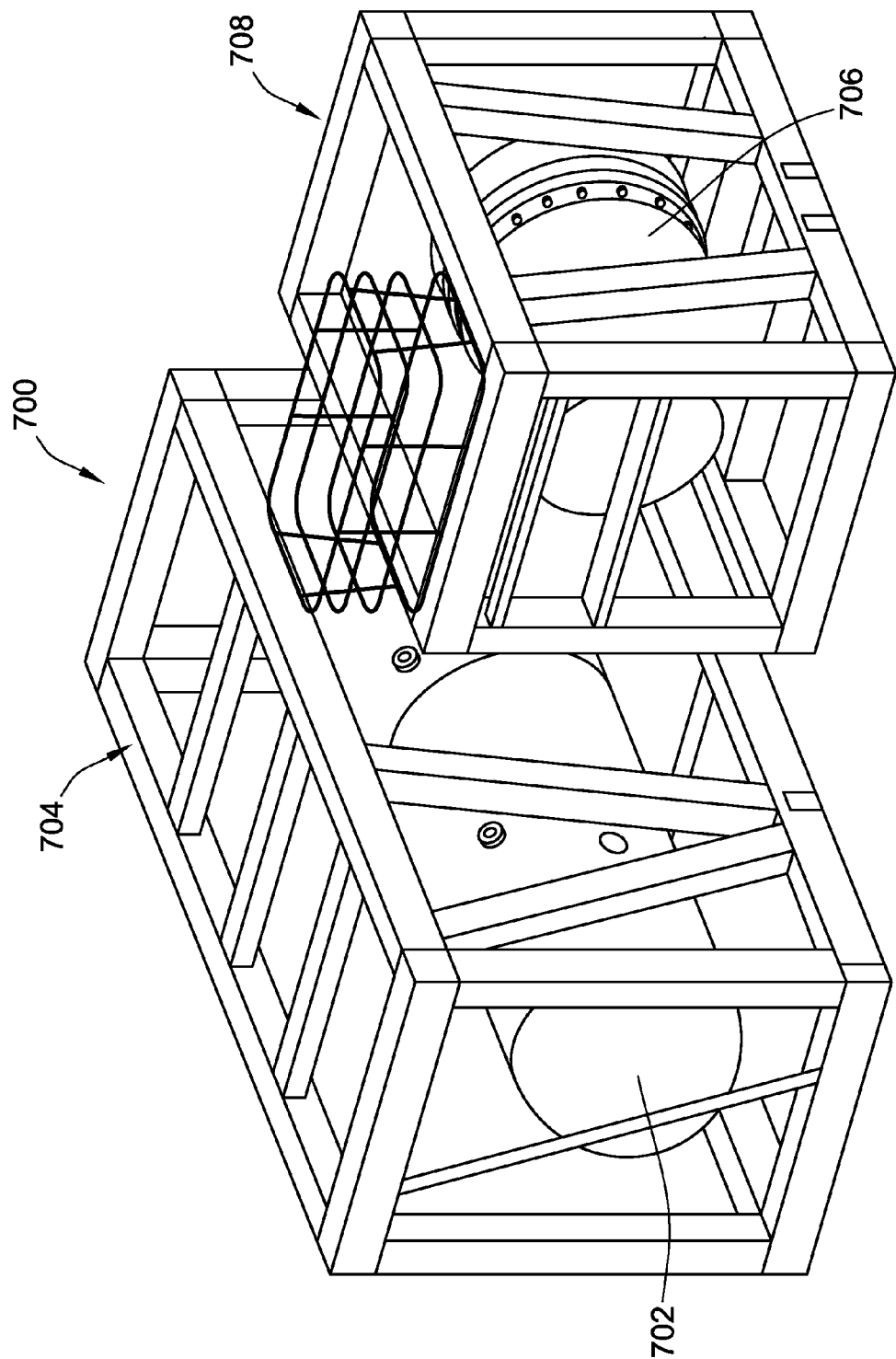


FIG. 21

**SUBSEA ELECTRICAL DISTRIBUTION
SYSTEM HAVING A MODULAR SUBSEA
CIRCUIT BREAKER AND METHOD FOR
ASSEMBLING SAME**

**CROSS-REFERENCE TO RELATED
APPLICATIONS**

[0001] This application claims priority to Provisional patent application No. 61/639,865, filed on Apr. 28, 2012, which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] 1. Field of the Invention

[0003] The present invention relates generally to subsea electrical systems and, more specifically, to a subsea electrical distribution system comprising a subsea circuit breaker.

[0004] 2. Description of the Related Art

[0005] This section is intended to introduce the reader to aspects of art that may be related to aspects of the present invention, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present invention. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

[0006] The petroleum industry has seen an increase in interest in the placement of pumping and/or processing equipment for fluids produced from subsea wells on the sea floor. Subsea pumping and processing system are particularly suited for challenging environments, such as the deep sea and Arctic, which are difficult to support from fixed platforms or floating production units. Subsea hydrocarbon production fields may comprise many subsea wells extending over hundreds of square miles. Therefore, subsea pumping and/or processing equipment may be required to be placed at several locations many miles apart.

[0007] Power for the subsea pumping and/or processing equipment must be supplied from a fixed platform, a floating production unit, or from land. Thus, power cables may be needed to cover extreme distances, possibly a hundred miles or more. The greater the number of pumping and/or processing units in a production field, the greater the number of power cables extending over these long distances are needed. Such systems are complicated and expensive.

SUMMARY OF THE INVENTION

[0008] A system and method for coupling electrical power subsea. The system comprises a subsea electrical distribution system having at least one modular circuit breaker assembly. The modular circuit breaker assembly is controlled by a control system that has a plurality of circuit breaker controls. Each circuit breaker is operable to be controlled by a plurality of circuit breaker controls and each circuit breaker control is operable to control a plurality of circuit breakers. Therefore, control of each circuit breaker is maintained even if a circuit breaker control fails. The system has extendable electrical connectors to facilitate connection of subsea electrical distribution system components.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Advantages of the invention may become apparent upon reading the following detailed description and upon reference to the drawings in which:

[0010] FIG. 1 is a schematic diagram of a subsea system, in accordance with exemplary embodiments of the present techniques;

[0011] FIG. 2 is a schematic diagram of a modular subsea electrical distribution system, in accordance with an exemplary embodiment of the present techniques;

[0012] FIG. 3 is a schematic diagram of a control and monitoring system for the modular subsea electrical distribution system of FIG. 2, in accordance with exemplary embodiments of the present techniques;

[0013] FIG. 4 is a block diagram of a subsea circuit breaker and redundant control and monitoring equipment for a modular subsea electrical distribution system, in accordance with exemplary embodiments of the present techniques;

[0014] FIG. 5 is a schematic diagram of a subsea circuit breaker and redundant control and monitoring equipment for a modular subsea electrical distribution system, in accordance with exemplary embodiments of the present techniques;

[0015] FIGS. 6 and 7 are perspective views of a modular subsea circuit breaker assembly for a subsea electrical distribution system, in accordance with exemplary embodiments of the present techniques;

[0016] FIG. 8 is a perspective view of a modular subsea circuit breaker for a modular subsea electrical distribution system, in accordance with exemplary embodiments of the present techniques;

[0017] FIG. 9 is a perspective view of a modular subsea circuit breaker assembly for a modular subsea electrical distribution system, in accordance with exemplary embodiments of the present techniques;

[0018] FIG. 10 is an elevation view of a modular subsea circuit breaker assembly and a pair of power cable harness assemblies having a retractable/extendable connector for a modular subsea electrical distribution system, in accordance with exemplary embodiments of the present techniques;

[0019] FIG. 11 is a perspective view of the power cable harness assembly of FIG. 10 with the retractable/extendable connector in the retracted position, in accordance with exemplary embodiments of the present techniques;

[0020] FIG. 12 is a perspective view of the power cable harness assembly of FIG. 10 with the retractable/extendable connector in the extended position, in accordance with exemplary embodiments of the present techniques;

[0021] FIG. 13 is a perspective view of the modular subsea circuit breaker assembly of FIG. 10 being removed and lifted from the modular subsea electrical distribution system, in accordance with exemplary embodiments of the present techniques;

[0022] FIG. 14 is a perspective view of the power cable harness assembly of FIG. 10 and an electrical load being removed and lifted from the modular subsea electrical distribution system, in accordance with exemplary embodiments of the present techniques;

[0023] FIG. 15 is a schematic diagram of a subsea modular electrical distribution system for a sea-based wind farm, in accordance with exemplary embodiments of the present techniques;

[0024] FIG. 16 is a simplified schematic diagram of the subsea electrical distribution system, in accordance with exemplary embodiments of the present techniques;

[0025] FIG. 17 is an elevation view of a prior art subsea circuit breaker and bus bar enclosure system

[0026] FIG. 18 is an elevation view of a modular circuit breaker assembly, in accordance with exemplary embodiments of the present techniques;

[0027] FIG. 19 is an elevation view of a penetrator assembly for a modular circuit breaker assembly, in accordance with exemplary embodiments of the present techniques.

[0028] FIG. 20 is a schematic diagram of a subsea system comprising a modular subsea electrical distribution system, in accordance with an alternative embodiment of the present techniques;

[0029] FIG. 21 is a perspective view of a modular subsea circuit breaker assembly, in accordance with an exemplary embodiment of the present techniques; and

[0030] FIG. 22 is an elevation view of a modular subsea electrical distribution system, in accordance with an alternative embodiment of the present techniques.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0031] One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, not all features of an actual implementation are described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill in the art and having the benefit of this disclosure.

[0032] Referring generally to FIG. 1, a system for providing electric power subsea is presented and referenced generally by reference numeral 30. In the illustrated embodiment, a surface facility 32 provides High voltage alternating current ("HV AC") electric power and control signals to a subsea electrical distribution system 34 via an umbilical cable 36. There is no set voltage value that defines what is "High voltage". However, in this embodiment, the voltage of HV AC provided by the umbilical is 110 kV AC or greater. In this embodiment, the surface facility 32 is located on land. However, the surface facility 32 may also be an off-shore platform or a vessel, such as a floating production and offloading ("FPO") vessel. As will be discussed in more detail below, the subsea electrical distribution system is a modular system that may be assembled in different configurations to meet system demands. In the illustrated embodiment, the subsea electrical distribution system 34 is configured to provide power to a first subsea load 38 and a second subsea load 40. The subsea electrical distribution system 34, as well as subsea loads 38, 40 may be located at extreme distances from the surface facility 32. For example, the subsea electrical distribution system 34 and subsea loads 38, 40 may be 150 km or more from the surface facility 32. In addition, the subsea electrical distribution system 34 and subsea loads 38, 40 may be located on an ocean floor several thousand feet below the surface of the ocean. Although only two subsea loads 38, 40 are shown in this embodiment, it is envisioned that many more subsea loads would receive power through the subsea electrical distribution system 34, rather than receiving power individually from the surface.

[0033] Referring generally to FIG. 2, the subsea electrical distribution system 34 is a modular system having a plurality of circuit breaker modules that may be connected together to form the system 34. The circuit breaker modules provide the system 44 with its modularity. The circuit breaker modules may be assembled and connected in a myriad of configurations to meet the demands of the subsea electrical distribution system 34. The circuit breaker modules are provided in the illustrated embodiment to enhance the flexibility and reliability of the subsea electrical distribution system 44.

[0034] In this embodiment, the subsea electrical distribution system 34 comprises a pair of central circuit breaker modules 42 that are configured to receive power and then distribute the power to a plurality of remote circuit breaker modules 44. The remote circuit breaker modules 44 may be located near the central circuit breaker modules 42 or at greater distances, such as tens of kilometers away. In this embodiment, the central circuit breaker modules 42 receive power from a first subsea umbilical 46 and a second subsea umbilical 48 for reliability. However, a single subsea umbilical may be used. As will be discussed in more detail below, the first and second subsea umbilicals 46, 48 comprise HV AC power cables, High voltage direct current ("HV DC") power cables, and fiber optic communication cables in this embodiment. As above, the HV AC carried by the umbilicals 46, 48 in this embodiment is 110 kV AC or greater. However, lower voltages may be provided. As with AC, there is no definitive DC voltage value that defines HV DC. In this embodiment, the HV DC carried by the umbilicals 46, 48 is between 2-10 kV DC. However, greater or lower DC voltages may be provided. The remote circuit breaker modules 44, in turn, are configured to provide power to a plurality of subsea electric loads 50. In the illustrated embodiment, the power received from the first umbilical 46 and a second umbilical 48 are reduced by a pair of subsea step-down transformers 52. However, power may be received at a lower voltage 36 kV), such that subsea step-down transformers are not required.

[0035] In this embodiment, the power received by the subsea electrical distribution system 34 is reduced by a pair of step-down transformers 52 before it is transmitted to the central circuit breaker modules 42. For example, the subsea transformers 52 may step-down the voltage of the HV AC electrical power from 110 kV AC to 36 kV AC. In this embodiment, the central circuit breaker modules 42 of the subsea electrical power distribution system 34 comprise a first circuit breaker module 54 and a second circuit breaker module 56. However, a single central circuit breaker module 42 may be used, particularly if only one umbilical is used. In this embodiment, the first circuit breaker module 54 receives power from the first umbilical 46 and the second circuit breaker module receives power from the second subsea umbilical 48. The first and second circuit breaker modules 54, 56 comprise a plurality of circuit breakers for selectively supplying electric power. The number of circuit breakers provided in each circuit breaker module may be varied depending upon the system requirements, such as the number of electrical loads to be supplied with power. In the illustrated embodiment, the first and second circuit breaker modules 54, 56 each comprise five circuit breaker assemblies 57, 58, 59, 60, 61. One side of each circuit breaker assembly 57, 58, 59, 60, 61 is connected to a common bus bar 62 and the other side of each circuit breaker assembly 57, 58, 59, 60, 61, the "free side", may be coupled to a power source or a load depending on the desired configuration. The first and second circuit

breaker modules **54**, **56** are configured in this embodiment so that the free side of circuit breaker assembly **57** receives power from one of the subsea umbilicals **46**, **48**. Power passes through circuit breaker assembly **57** to the bus bar **62**. Circuit breaker assembly **57** is used to selectively connect and disconnect the bus bar **62** from power coming from one of the subsea umbilicals **46**, **48**. The free side of circuit breaker assemblies **58**, **59**, **60**, and **61** of the first and second circuit breaker modules **54**, **56** are either coupled to remote circuit breaker modules **44**, loads, or not connected to anything for use as a spare.

[0036] The remote circuit breaker modules **44** comprise a third circuit breaker module **64** that comprises three circuit breaker assemblies **57**, **58**, **59**, rather than five. In this configuration, the third circuit breaker module **64** is connected to the free side of circuit breaker assembly **58** of the first circuit breaker module **54**. This enables power to be provided to the bus bar **62** of the third circuit breaker module **64** from the first circuit breaker module **54**. The free sides of circuit breaker assemblies **57**, **58**, **59** of the third circuit breaker module **64** are coupled to loads **50**. The three circuit breaker assemblies **57**, **58**, **59** of the third circuit breaker module **64**, thus, are operable to selectively connect and disconnect the loads **50** and the bus bar **62** of the third circuit breaker module **64**.

[0037] The remote circuit breaker modules **44** are configured to receive power from either subsea umbilical **46**, **48**. In this embodiment, the remote circuit breaker modules **44** also comprise a fourth circuit breaker module **66**, a fifth circuit breaker module **68**, and a sixth circuit breaker module **70**. Circuit breaker assembly **57** of the fourth circuit breaker module **66** is coupled to circuit breaker assembly **59** of the first circuit breaker module **54**. This enables power to be provided to the bus bar **62** of the fourth circuit breaker module **66** from the first subsea umbilical **46** via circuit breaker **57** of the fourth circuit breaker module **66**. In addition, circuit breaker assembly **61** of the fourth circuit breaker module is connected by a link **72** to circuit breaker assembly **57** of the fifth circuit breaker module **68**. Circuit breaker assembly **61** of the fifth circuit breaker module **68** is coupled to circuit breaker assembly **59** of the second circuit breaker **58**. This enables power to be provided to the bus bar **62** of the fifth circuit breaker module **68** from the second subsea umbilical **48** via circuit breaker assembly **61** of the fifth circuit breaker module **68**. Thus, by selectively operating circuit breaker assembly **57** of the fourth circuit breaker module **66** and circuit breaker assembly **61** of the fifth circuit breaker module **68**, power may be provided to bus bars **62** of the fourth and fifth circuit breaker modules **66**, **68** from either the first subsea umbilical **46** or the second subsea umbilical **48**. Alternatively, the sixth circuit breaker module **70** is coupled to both the first and second circuit breaker modules. By selectively operating circuit breaker assembly **57** and circuit breaker assembly **61** of the sixth circuit breaker module **70**, power may be supplied to the bus bar of the sixth circuit breaker module **70** from either the first umbilical **46** or the second umbilical **48** via the first and second circuit breaker modules **54**, **56**.

[0038] The subsea electrical distribution system **44** may be used to provide power to a variety of loads **50**, rather than routing power directly to each load **50** from the surface. This greatly simplifies power distribution. In this embodiment, each of the loads **50** comprises an additional step-down transformer **76** to supply power to a variable speed drive (“VSD”) **78**. The VSD **78** provides variable speed electric power to a

motor **80** to drive a pump **82**. Similarly, a load **50** may be a variable frequency drive (“VFD”). The pumps **82** may be used to pump fluids from a subsea well to a processing unit, for example. However, the VSDs may be used to drive subsea compressors, as well.

[0039] Referring generally to FIG. 3, operation of the subsea electrical distribution system **34** is controlled by a control and monitoring system **84**. In the illustrated embodiment, a computer system **86** is used to enable a user to manage the subsea electrical distribution system **34** via the control and monitoring system’s HMI (Human Machine Interface). The computer system **86** may be located on-shore or at sea aboard a platform or vessel. The computer **86** may be used to transmit the user’s close and open circuit breaker orders, automatically vary the speed of the VSDs, and perform other control functions. In addition, sensors may be coupled to the computer system **86** to provide the user with information to facilitate operation of the subsea electrical distribution system **34** and loads **50**.

[0040] In the illustrated embodiment, the subsea umbilicals **46**, **48** also include communication lines **88**, which enable communication between the computer system **86**, the subsea electrical distribution system **34** and loads **50**. Preferably, the communication lines **88** are fiber optic cables routed along with HV AC and DC power cables in the umbilicals **46**, **48**. The umbilicals **46**, **48**, are terminated at a subsea umbilical termination assembly (“SUTA”) **90** in this embodiment. From each SUTA **90**, communication lines **88** are routed to protection and control modules **92** corresponding to each of the circuit breaker modules **54**, **56**, **64**, **66**, **68**, **70**. Each of the protection and control modules **92** has an Ethernet switch **94** that receives the fiber optic lines **88** in the illustrated embodiment. In the illustrated embodiment, the communication is based on use of functionality described IEC 61850. Reports are used to transmit information to the user for monitoring purposes. Control functions are executed by means of Generic Object Oriented Substation Events (GOOSE). GOOSE messages are also used for protection where communication between protection relays is required such as for subsea cables **72**, **74**. The use of IEC 61850 allows all communication required for protection, control and monitoring to transit via the fiber optic cables installed within the umbilicals and subsea cables. This avoids having to install additional cables for protection, monitoring and control.

[0041] In addition, each protection and control module **92** comprises a protection relay **96** and one or more programmable logic controller functions (PLCs) **98**. In addition to the protection functions, the protection relay **96** also comprises monitoring equipment for the subsea electrical distribution system **34**, such as circuit breaker conditions, and the plurality of loads **50**. The PLC functions **98** are used to control the circuit breaker assemblies **58**, **60**. The protection relay **96** is operable to provide a signal to the PLC functions **98** to trip the circuit breakers when an undesired condition is reached, such as an overload condition. The protection relay provides direct tripping of the circuit breaker for electrical faults. The Ethernet switch **94** routes communications between the computer system **86**, the protection relay **96**, and the PLC functions **98**. The PLC functions can be housed in discrete pieces of equipment or can be integrated into another electronic device such as a protection relay. The “PLC” function can have different embodiments.

[0042] Referring generally to FIGS. 4 and 5, detailed views of the first circuit breaker module **54** and its corresponding

protection and control module 92 are presented. Circuit breakers assembly 57 comprises a circuit breaker 102. Similarly, circuit breaker assembly 58 comprises a circuit breaker 104. In the illustrated embodiment, each of the circuit breakers assemblies 57, 58 is connected to two protection and control modules 92 for redundant protection: a first control unit 106 and a second control unit 108. The first control unit 106 and second control unit 108 are operable to selectively open and close circuit breakers 102, 104. If one control unit 106, 108 fails, the other control unit 108, 106 can still selectively open and close both circuit breakers 102, 104. Each protection and control module 92 has a main relay and an auxiliary relay function that control the opening and closing of circuit breakers 102, 104. For example, the first control unit 106 has a main relay function 110 and an auxiliary relay function 112. Similarly, the second control unit 108 has a main relay function 114 and an auxiliary relay function 116. The main relay function of a control unit is connected to one circuit breaker, while the auxiliary relay function is connected to a second circuit breaker. For example, main relay function 110 of the first control unit 106 is connected to circuit breaker 102 and the auxiliary relay function 112 is connected to circuit breaker 104. Similarly, circuit breaker 104 is connected to the main relay function 110 of control unit 106 and the auxiliary relay function 116 of control unit 108. If control unit 106 fails, circuit breaker 102 can still be controlled by auxiliary relay function 116 of control unit 108. In the illustrated embodiment the main relay function and the auxiliary relay function are housed in the same piece of equipment, known as a control unit.

[0043] As best illustrated in FIG. 5, circuit breakers are opened and closed by closing coils and trip coils, respectively. Each circuit breaker assembly has a spring-charged mechanism for opening and closing the circuit breaker and the circuit breaker closing coils and trip coils control the spring-charged mechanism. If a circuit breaker is open and the closing coil is energized, the spring-charged mechanism will close the circuit breaker. Similarly, when the circuit breaker is closed and the trip coil is energized, the spring-charged mechanism will open the circuit breaker. In the illustrated embodiment, each circuit breaker has redundant trip coils and closing coils. Surface circuit breakers have only a single closing coil. However, because of the difficulty in removing a circuit breaker module from subsea if the closing coil were to fail, two closing coils are provided in each circuit breaker in this embodiment. Circuit breaker assembly 57 has a first trip coil 118 and a first closing coil 120 that are connected to the main relay function 110 of control unit 106. In addition, circuit breaker assembly 57 has a second trip coil 122 and a second closing coil 124 that are connected to the auxiliary relay function 116 of the second control unit 108. Either trip coil 118, 122 can open the circuit breaker 102 and either closing coil 120, 124 can close the circuit breaker 102. A first electric motor 126 and a second electric motor 127 having separate power supplies are provided to energize the spring-charged mechanism 128 when the spring is discharged. A surface circuit breaker has only a single motor 126. However, because of the difficulty in repairing/replacing a subsea circuit breaker if the motor 126 fails, motors 126, 127 with separate power supplies are provided for reliability in this embodiment.

[0044] Referring generally to FIGS. 4 and 5, the protection and control modules 92 also are connected to sensors within the circuit breaker assemblies 57, 58. For example, the main

relay function 110 of the first control unit 106 is connected to a first set of phase current sensors 130 and a first zero-sequence current sensor 132. The auxiliary relay function 114 of the second control unit 108 is connected to a second set of phase current sensors 134 and a second zero-sequence current sensor 136. Similarly, the main relay function 114 of the second control unit 108 is connected to a first set of phase current sensors 138 and a first zero-sequence current sensor 140 associated with the second circuit breaker assembly 58. The auxiliary relay function 112 of the first control unit 106 is connected to a second set of phase current sensors 142 and a second zero-sequence current sensor 144 associated with the second circuit breaker 58.

[0045] Referring generally to FIGS. 6 and 7, an embodiment of a modular subsea circuit breaker assembly 146 for housing a circuit breaker assembly 147 for use in the subsea electrical distribution system 34 of FIGS. 1-5 is presented. The circuit breaker assembly 147 is housed within a watertight enclosure 148. The enclosure 148 protects the internal components from seawater. One end of the enclosure 148 has a gas sealing barrier 149 and the other end has a circuit breaker operating mechanism enclosure 150. The circuit breaker operating mechanism enclosure 150 has a series of connections 151 for connection to the control and monitoring system 84. In addition, the enclosure 148 has three sealed openings 152 called "penetrators" to which each phase of a three-phase power cable may be connected for connection to the circuit breaker assembly 147. In addition, in this embodiment, the enclosure 148 is filled with sulfur hexafluoride (SF_6) gas to a pressure of two atmospheres for electrical insulation between the circuit breaker assembly 147 and the enclosure 148.

[0046] In the illustrated embodiment, the circuit breaker assembly 147 is a three-phase circuit breaker. Each phase of the three-phase power has its own circuit breaker pole 153. Within each circuit breaker pole 153 is SF_6 gas to quench arcing between contacts when opening and closing the circuit breakers due to the large voltages utilized in the subsea electrical distribution system 34. A circuit breaker pole using vacuum for arc quenching can also be used. External electrical power cables are connected to the penetrators 152 on the enclosure 148 for internal connection to three terminals 154 on the circuit breaker assembly 147. Each circuit breaker pole 153 has a conductor 155 that extends through the gas sealing barrier 149 of the enclosure 148 into a bus bar compartment to which the modular circuit breaker assembly 146 is secured.

[0047] Referring generally to FIG. 8, an embodiment of the first circuit breaker module 54 is presented. In this embodiment, the first circuit breaker module 54 comprises five modular circuit breaker assemblies 146 connected to a bus bar assembly 162 housing the bus bar 59 (not shown). The bus bar assembly 162 is comprised of two end assemblies 164 connected to a central assembly 166. However, additional central assemblies 164 may be connected together to extend the bus bar assembly 162. The interior of the bus bar assembly 162 is insulated with SF_6 gas in this embodiment. As will be discussed in more detail below, the use of SF_6 gas for insulation, rather than oil, enables a smaller bus bar assembly 162 to be used, as well as requiring fewer penetrations through barriers that have to withstand differential pressure. Each of the modular circuit breaker assemblies 146 has a connector 168 for connecting to a power cable. Each of the connectors 168 is connected to a penetrator 152 which seals the opening in the enclosure 148.

[0048] In the illustrated embodiment, the first circuit breaker module 54 comprises a first modular circuit breaker assembly 170, a second modular circuit breaker assembly 172, a third modular circuit breaker assembly 174, a fourth modular circuit breaker assembly 176, and a fifth modular circuit breaker assembly 178. In this embodiment, circuit breaker 57 (not shown) is housed within the first modular circuit breaker assembly 170. Circuit breaker 58 (not shown) is housed within the second modular circuit breaker assembly 172. Circuit breaker 59 (not shown) is housed within the third modular circuit breaker assembly 174. Circuit breaker 60 (not shown) is housed within the fourth modular circuit breaker assembly 176. Finally, circuit breaker 61 (not shown) is housed within the fifth modular circuit breaker assembly 178. Opposite the third modular circuit breaker assembly 174 is a spare space for an additional modular circuit breaker assembly. This would bring the total number of circuit breakers to six if this spare space was used.

[0049] Referring generally to FIG. 9, the first circuit breaker module 54 is housed within a supporting structure 180 in the illustrated embodiment. The supporting structure 180 comprises a frame 182 in which the first circuit breaker module 54 is supported. In addition, the supporting structure 180 is adapted to route power to and from each of the modular circuit breaker assemblies 146 of the first circuit breaker module 54. The first circuit breaker module 54 is configured by routing power either to or from each modular circuit breaker assembly 146. Connector assemblies 184 are disposed around the frame 182. The supporting structure 180 also comprises a plurality of power cables 186 that extend between the connector assemblies 184 and the connectors 168 on the circuit breaker assemblies 170, 172, 174, 176, 178 to route power to and from the modular circuit breaker assemblies 170, 172, 174, 176, 178. Each connector assembly 184 is configured with three wet mate power connectors 188 together with alignment guides 190. The alignment guides 190 align the power connectors 188 with a corresponding external wet mate connector assembly (not shown). Each power cable 186 is routed between a wet mate power connector 188 and a wet mate connector 168 on a circuit breaker assembly 170, 172, 174, 176, 178 in this embodiment. In addition, the supporting structure 180 has a plurality of guides 191 for alignment purposes. A cable clamp 192 is mounted on the circuit breaker module to support the cable at its connection 168. The clamp 192 is designed to securely hold the cable at varying external pressures from sea level to the final installation depth under water.

[0050] Referring generally to FIGS. 10-12, in the illustrated embodiment, each circuit breaker assembly 170, 172, 174, 176, 178 is connected to an external component of the subsea electrical distribution network via a subsea cable 208 by connecting a cable harness assembly 200 having a set of wet mate connectors 202 that may be extended and retracted to that modular circuit breaker assembly's connector assembly 184. The connector 202 of FIG. 11 and the left side of FIG. 10 is shown in the retracted position. The connector 202 of FIG. 12 and the right side of FIG. 10 is shown in the extended position. In this embodiment, the cable harness assembly 200 also comprises a frame 204, and a cable harness 206 for securing power cables 208 to the cable harness assembly 200. The frame 204 has a plurality of guides 209 for alignment purposes.

[0051] To connect the power cables 208 of the cable harness assembly 200 to the circuit breaker module assembly

180, the frame 204 of the cable harness assembly 200 is disposed adjacent to the frame 182 of the circuit breaker module assembly 180 so that the connector 202 is generally aligned with, and proximate to, the connector assembly 184. In this embodiment, the frame 182 of the circuit breaker module assembly 180 and the frames 204 of the cable harness assemblies 200 are disposed on a template 210. The template 210 has guideposts (not shown) configured to receive the guides 191 in the frame 182 of the supporting structure 180 and the guides 209 of the cable harness assemblies 200 so that the cable harness assemblies 200 and supporting structure 180 are in proper alignment. Each cable harness assembly is independent of the frame 182 and all other cable harnesses.

[0052] An ROV (not shown) is used to extend the connector 202 towards the connector assembly 184 of the circuit breaker module 180 to make the connection. The cable harness assemblies 200 have a connector guide assembly 211 comprising a fixed portion 212 secured to the frame 204 and a movable portion 213 secured to the power cables 208. The ROV (not shown) may secure to the frame 204 and grab the movable portion 213 and either pull or push the movable portion 213, and power cables 208, relative to the frame to retract or extend the connectors 202. As the connector 200 is extended, guide pins 214 on the connector 200 engage the guides 190 on the connector assembly 184 of the circuit breaker module assembly 180. The engagement between the guide pins 214 and the guides 190 brings the wet mate connectors 214 of the connector 200 into alignment with wet mate connectors 188 of the first circuit breaker module 54. Eventually, as the connector 202 is extended, the connectors 214 of the connector 202 of the cable harness assembly 200 connect to the connectors 188 of the first circuit breaker module assembly 54, electrically coupling the power cables 208 to the cables 186 of the supporting structure 180 of the first circuit breaker module assembly 54. Similarly, to disconnect the power cables 208 of the cable harness assembly 200 from the circuit breaker module assembly 180, an ROV (not shown) is used to retract the connector 202 to disengage from the connector assembly 184 of the supporting structure 180 of the first circuit breaker module 54.

[0053] Referring generally to FIG. 13, because the cable harness assemblies 200 are selectively connectable to the supporting structure 180, a circuit breaker module assembly 180 may be removed from the subsea electrical distribution system 34 for repair/modification without requiring removal of loads 50 or other cables 208 routed to and from the circuit breaker modules. In this view, the circuit breaker module and supporting structure 180 are guided into and out of position by an ROV 219 on to the template 210. In addition, the cable harness assemblies 200 may be disconnected to facilitate fault detection. For example, after a connector 202 has been disconnected, an ROV may connect to the connectors 202 to perform test to identify if a fault exists in the power cable 208 or if the fault exists in the circuit breaker module 54. Alternatively, the ROV can check power cable electrical characteristics.

[0054] Referring generally to FIG. 14, similarly, a cable harness assembly 200 and connected cable 208 (not shown) may be removed from the subsea electrical distribution system 34 for repair/modification without requiring removal of the first circuit breaker module assembly 54 or other cables 208 routed to and from the circuit breaker module. To remove a cable harness assembly 200 from the subsea electrical distribution system 34, the retractable/extendable connector 202

for its cable harness assembly **200** is retracted; this disconnects the cable harness assembly **200** and connected cable **208** from the circuit breaker module assembly **180**. The cable harness assembly **200**, and the cables **208** connected to the cable harness assembly **200** may then be raised to the surface for repair/modification. The cable harness assembly **200** is guided into and out of position by the ROV onto the template **210**. If the load **50** remains connected to the cable **208** then it may be raised to the surface for repair/modification together with the cable harness assembly **200** and connected cable **208**.

[0055] Referring generally to FIG. 15, a wind farm **250** having a modular subsea electrical distribution network **252** is presented. In the illustrated embodiment, the wind farm **250** comprises a plurality of wind turbine-generators **254**. In this embodiment, groups **256** of wind turbine-generators **254** are electrically connected to a “local” modular subsea circuit breaker assembly **258**. The modular subsea circuit breaker assemblies **258** have the features and characteristics as described above in respect to FIGS. 2-14, as described above. In this embodiment, each wind turbine-generator **254** is connected to a corresponding circuit breaker **260** within a modular subsea circuit breaker assembly **258**. In turn, groups **262** of modular subsea circuit breaker assemblies **258** are connected to a “regional” modular subsea circuit breaker assembly **264**. The “regional” modular subsea circuit breaker assemblies **264** are connected to a “central hub” modular subsea circuit breaker assembly **266**. The “central hub” modular subsea circuit breaker assembly **266** is connected to a step-up transformer **268** to increase the voltage of the power generated by the wind turbine-generators **254** to a high-voltage for transmission over a subsea umbilical **270** to a shore facility **272**.

[0056] Referring generally to FIG. 16, in addition to HV AC power and communications lines, the subsea electric system **30** also couples HV DC to, and through, the subsea power distribution system **34**. In this embodiment, HV DC is typically between 2 kV and 10 kV. Previously, HV DC was coupled to subsea loads in either a separate umbilical or produced subsea from HV AC transmitted subsea via an umbilical. However, in the illustrated embodiment, the first umbilical **46** is configured with HV AC power cables, HV DC power cables, and fiber optic cables for communication. At the SUTA **90**, HV AC power is coupled from the umbilical **46** to provide power to loads **50** via a HV AC power cable **300**. In addition, HV DC power is coupled from the umbilical **46** to a protection and control module **92** by a HV DC power cable **301**. Finally, communication capability is coupled from the umbilical **46** to the protection and control module **92** by a fiber optic cable **302**. Communication capability is provided to process equipment **303** from the protection and control modules **92** via a fiber optic cable **302** and a subsea communication interface **304**. In addition, the protection and control module **92** provides DC auxiliary power to the process equipment via an auxiliary DC power cable **305**.

[0057] Referring generally to FIG. 17, a representative subsea breaker and bus bar assembly is disclosed, and represented generally by reference numeral **310**. The illustrated assembly **310** has a first circuit breaker **312** and a second circuit breaker **314**. The first circuit breaker **312** has an enclosure **316** and the second circuit breaker **314** has an enclosure **318**. The interiors of both enclosures **316**, **318** is pressurized with SF₆ gas **320**. The pressure of the gas **320** may be near atmospheric pressure. Therefore, there will be a large differential pressure between the interior of the enclosures **316**, **318**

and the seawater **322** pressure surrounding the assembly **310** when the assembly **310** is located subsea. The assembly **310** also comprises a bus bar **324** housed within a two-stage pressure compensation housing **325**. The bus bar **324** is housed within a first enclosure **326**. The first enclosure **326**, in turn, is housed within a second enclosure **328**. The first enclosure **326** is filled with a first oil **330** and the second enclosure **328** is filled with a second oil **332**. The viscosities of the oils **330**, **332** may vary. The pressure compensation reduces, if not eliminates, the pressure differential between the interior of the first enclosure **326** and seawater **322**. However, it produces a pressure differential between the oil **330** within the interior of the first enclosure **326** and the SF₆ gas **320** within the interior of the circuit breaker enclosures **316**, **318**, which may lead to leaks of oil into the interior of the circuit breaker enclosures **316**, **318**. In addition, this requires two sealed penetrations, a first penetration **334** and a second penetration **336**, to connect to the bus bar **324**, creating potential leak paths.

[0058] Referring generally to FIG. 18, a simplified drawing of circuit breaker module **54** of FIG. 8 is presented. In this embodiment, rather than pressure compensating the interior **338** of the bus bar assembly **162** to seawater pressure, the interior **338** of the bus bar assembly **162** is pressurized with SF₆ gas **320** to a pressure of two atmospheres. The SF₆ gas **320** is a better electrical insulator than oil **330**, **332**. Therefore, the interior **338** of the bus bar assembly **162** requires less volume for electrical insulation between the bus bar **62** and the enclosure **340** of the bus bar assembly **162**. Thus, the size of the enclosure **340** may be reduced. In addition, the differential pressure between the gas-filled interior **338** of the bus bar assembly **162** and the gas-filled interior **342** of the circuit breakers assemblies **168**, **170** is reduced, if not eliminated, reducing potential for leaks between the bus bar assembly **162** and the circuit breaker assemblies **168**, **170**. This also reduces the number of sealed penetrations **344** needed between the bus bar **62** and a circuit breaker **57**, **58** by one, reducing potential leak paths.

[0059] Referring generally to FIG. 19, an embodiment of a penetrator **344** is presented. In this embodiment, a conductor **155** from a circuit breaker **57**, **58**, etc., extends through an opening **346** in the pressure barrier **149** between the interior and exterior gas or fluids at various pressure ratings. In this embodiment, the penetrator **344** comprises insulation **348** surrounding the conductor **155** and a body **350** that completes the seal against the opening **346** in the pressure barrier **149**. The body **350** also comprises a boot **352**. In this embodiment, the boot **352** also comprises a first current sensor **354** and a second current sensor **356** integrated into the boot **352**. The current sensors **354**, **356** comprise a sensor core **358**, a sensor winding **360**, and sensor insulation **362**. The current sensors **354**, **356** may be current transformers.

[0060] Referring generally to FIG. 20, a subsea system is presented and represented generally by reference numeral **400**. In this embodiment, the subsea system **400** comprises a modular subsea electrical distribution system **402** operable to provide HV AC, Low voltage alternating current (“LV AC”), HV DC, Low voltage direct current (“LV DC”), and fiber optic communication lines to power and control subsea loads.

[0061] In the illustrated embodiment, a HV AC power cable **300**, a HV DC power cable **301**, and a fiber optic communication line **302** are coupled to a modular HV Subsea Substation (“HVSS”) **404** comprising a circuit breaker module **406** and a protection and control module **408**. The HV AC power

cable 300 is coupled to the subsea circuit breaker module 406. The subsea circuit breaker module 406 comprises circuit breaker assemblies 57, 58, 59, 60, 61, and a busbar assembly 62, as described above in FIG. 2. The HV DC power cable 301 and fiber optic communication line 302 are coupled to a control and monitoring module 408. In this embodiment, the control and monitoring module 408 comprises a HV DC power and fiber optic communication line interface 410. DC power and communication signals are coupled to a protection and control module 412. The protection and control module 412 is, in turn, coupled to the circuit breaker module 406. The protection and control module 412 is similar to protection and control module 92 described above in FIGS. 3-5.

[0062] In this embodiment, the subsea electrical distribution system 402 comprises a LV subsea distribution ("LVSD") module 414 operable to supply LV AC power to various loads from the HV AC power and/or the HV DC power supplied by the umbilical 46. HV AC power from the HVSS is coupled to a subsea transformer 416 via circuit breaker assembly 61. The transformer 416 steps-down the HV AC from approximately 33 kVAC to approximately 690 VAC, which is coupled to the LVSD module 414. The illustrated embodiment of the LVSD module 410 comprises a first busbar assembly 418 and a second busbar assembly 420 coupled together by a cross-connect circuit breaker assembly 422. LV AC power from the transformer 416 is coupled to the first busbar assembly 418 by a first inlet circuit breaker assembly 424. LV AC power is supplied to the second busbar assembly 420 from an uninterruptible power supply ("UPS") module 426 through a circuit breaker assembly 428 in the LVSD module 414. The UPS receives HV DC power and fiber optic communication lines from the HV DC power and fiber optic communication line interface 410. In addition, in the illustrated embodiment, the UPS module 426 comprises an emergency battery 430 operable to provide emergency DC power if power from the umbilical 46 is lost. The UPS module 426 comprises a DC to AC power supply 432 that converts DC power from either the umbilical 46, via the communication and monitoring module 408, or the emergency battery 430 to LV AC. In addition, the UPS module 426 comprises a DC to DC power supply 434 for providing DC power to loads from either umbilical, via the communication and monitoring module 408, or the emergency battery 430.

[0063] The LVSD module 414 comprises a plurality of circuit breaker assemblies 436. Some of the circuit breaker assemblies are coupled to the first busbar assembly 418 and some are coupled to the second busbar assembly 420. Depending upon the position of the cross-connect circuit breaker assembly 422, power may be supplied to the circuit breaker assemblies 436 from the HVSS 404 and/or the UPS module 426. In this embodiment, the power supplied by the UPS module 426 is considered as "Secure Power" meaning that it is available when the normal AC power has failed. In this embodiment, during normal operation, the cross-connect circuit assembly 422 is open and circuit breaker assembly 428 is closed so that the circuit breaker assemblies are supplied power by the HVSS 404 and the UPS 432. However, when there is a loss of power from the UPS module 432, the cross-connect 422 is closed and circuit breaker assembly 428 is opened so that the AC power from the HVSS 404/umbilical 46 may supply power to critical loads that must remain energized. In this embodiment, each circuit breaker assembly 436 couples power to subsea loads via an isolation transformer 438. The outgoing circuits of the LVSD module 426 are

provided with isolation transformers 438 in order to allow loads to continue to be supplied should an earth fault occur on the load side of the isolation transformer 438.

[0064] The monitoring and control of the devices within the LVSD module 414 is performed via fiber optic cables 302 connected to the CMM 408. In addition, sensors installed on the step-down transformer 416 are connected to the LVSD module via subsea cable 440. The LVSD module 414 converts signals from these sensors to optical signals for transmission via the fiber optic cables 302 connecting the LVSD module 414 to the CMM 408 and, thus, to other subsea equipment and the shore station.

[0065] The subsea system 400 also comprises a subsea heating system 442. The subsea electrical distribution system 402 comprises a heat tracing module ("HTM") 444 for supplying LV AC power to the heating system 442. The HTM 444 is a LV AC switchgear module dedicated to the subsea heating system 442. High power subsea heating circuits 446 used for initial heating are supplied by the HVSS 404 via a power cable 450 coupled to the first busbar 418 of the LVSD module 414. Lower power circuits 448 used for maintaining a temperature are supplied by a power cable 452 coupled to the second busbar 420 of the LVSD module 414 and, therefore, may be supplied by the UPS module 426 if power from the HVSS 404 is lost. The HTM 444 also comprises a plurality of isolation transformers 454. The isolation transformers 454 in the HTM 444 are used for two purposes. The first purpose is to allow continued operation in case of an earth fault on the load side of the transformer 454. The other purpose is to adapt the output voltage to that required by the heating system 442. For example, the heating system 442 may require voltages of greater than 1000 V AC. This second purpose may be a new idea for a subsea heating power supply. The LVSD module 414 also communicates with the HTM 442 via fiber optic cables 302. This allows the HTM 444 to be monitored and remotely controlled in the same manner as the LVSD module 414. Similarly any sensors in the heating system 442 can be connected to devices within the HTM 444 and converted to optical signals for transmission to other subsea equipment or to the shore station.

[0066] LV AC also is supplied to a VFD assembly 456 in this embodiment. The VFD assembly 456 receives main HV AC power from the HVSS 404. In the illustrated embodiment, LV AC from the first busbar 418 of the LVSD module 414 is provided to the VFD assembly 456 to power a pre-charge and pre-magnetization transformer 458 located within the VFD assembly 456. This transformer 458 must be energized before main AC power from the HVSS is energized. In previous subsea VFD systems, power to a pre-charge and pre-magnetization transformer of a VFD was provided from a subsea or topside UPS. In this embodiment, only normal AC power is required, not secure power. LV AC power from the HVSS 404 via the first busbar 418 is provided to secondary functions 460. Secure power from the second busbar 420 is provided to primary functions 462, such as the control electronics of the VFD and for cooling fans, if provided. A power cable 464 is provided to couple LV AC power from the first busbar 418 to the secondary functions and a separate power cable 466 is provided to couple secure LV AC power from the second busbar 420 to the main functions 462.

[0067] The subsea system 400 also comprises a magnetic bearing module ("MBM") 480, which supplies power to a magnetic bearing 482 for a rotating device. The VFD 456 is used to power an electric motor 80, which, in turn, may be

used to drive a number of different rotating devices, such as a subsea pump **483** or subsea compressor **484**. The subsea pump **483** may be used to pump production fluids from a subsea well to a platform, vessel, or shore facility. The subsea compressor **484** may be used to compress production gases from a subsea well, which may be piped to a platform, vessel, or shore facility. The magnetic bearing **482** provides support for the rotating shafts of the rotating devices powered by the VFD **456**. In this embodiment, the MBM **480** may receive DC power from the UPS module **426** or LV AC from the LVSD module **414**. A DC power cable **486** couples DC power from the UPS module **426** to the MBM **480**. An AC power cable **488** couples AC power from the LVSD module **414** to the MBM **480**.

[0068] In the illustrated embodiment, the subsea system **400** comprises a subsea control module (“SCM”) **500**. The SCM **500** controls the subsea production and processing equipment. In this embodiment, the SCM **500** comprises a subsea electrical module (“SEM”) **502**. In previous designs, the SCM **500** and its embodied SEM **502** received power directly from a shore facility via a separate power cable. In this embodiment, main function controller **504** of the SEM **502** receives secure power from the second busbar **420** of the LVSD module **414**. Secondary function controller **506** receives power from the first busbar **418** of the LVSD module **414**. As noted above, secure power from the second busbar **420** of the LVSD module **414** may be LV AC power stepped-down from the HV AC power of the umbilical **46** or AC power converted either from the HV DC power in the umbilical **46** or emergency battery **430** in the UPS module **426**. A power cable **510** is provided to couple LV AC power from the first busbar **418** to the secondary function controller **506** and a separate power cable **512** is provided to couple secure LV AC power from the second busbar **420** to the main function controller **504**.

[0069] In addition, the subsea electrical distribution system **402** provides power to motor-operated valves and actuators, represented generally by reference numeral **520**. One or more of the motor-operated valves and actuators **520** may be powered by LV AC from the first busbar **418** of the HVSS **414**. In addition, one or more of the motor-operated valves and actuators **520** may be powered by secure power from the second busbar **420** of the LVSD module **414**. Secure power may be LV AC power stepped-down from the HV AC power of the umbilical **46** or AC power converted either from the HV DC power in the umbilical **46** or emergency battery **430** in the UPS module **426**. A power cable **522** is provided to couple LV AC power from the first busbar **418** to the motor-operated valves and actuators **520** and a separate power cable **524** is provided to couple secure LV AC power from the second busbar **420** to the motor-operated valves and actuators **520**.

[0070] In addition, in this embodiment, the subsea electrical distribution system **402** provides power to a subsea tree **530** via a power cable **532**. The subsea tree **530** monitors and controls the production of fluids from a subsea well. The subsea tree **530** is secured to a subsea wellhead (not shown) of a completed subsea well. The subsea tree **530** has valves that control the flow of fluids flowing from the subsea well or gas or water injected into the subsea well. In this embodiment, the valves controlling flow to, from, and through the subsea tree **530** are operated using electric operators powered from the power cable **532** of the subsea electrical distribution system **402**. However, the electric operators may be powered with DC power from the DC module **426**. In addition, a fiber optic

cable **302** is routed to the subsea tree **530** to enable the subsea tree **530** to be controlled from the surface.

[0071] Referring generally to FIG. 21, an embodiment of a modular subsea circuit breaker assembly for use with the subsea electrical distribution system described above is presented and represented generally by reference numeral **700**. In this embodiment, a subsea circuit breaker assembly **702**, such as one of the circuit breaker assemblies **54**, **56**, **64**, **66**, **68**, **70** of FIG. 2, is supported by a frame **704**. In addition, a protection and control module **706**, such as protection and control module **92** of FIG. 3, is supported by a frame **708**. The protection and control module **706** may be connected to the circuit breaker assembly **702** by disposing the protection and control module **706** and frame **708** proximate to the circuit breaker assembly **702** and frame **704** and connecting cables between the protection and control module **706** and the circuit breaker assembly **702**. Either the protection and control module **706** or circuit breaker assembly **702** may be replaced by disconnecting the cables connecting them together and lifting the device to be replaced to the surface. A replacement device may be lowered to the position of the original device and the electrical cable re-connected. Subsea cables and flying leads are connected and disconnected by means of an ROV (not shown).

[0072] Referring generally to FIG. 22, an alternative embodiment of a modular subsea electrical distribution system **800** is presented. As above, the busbar assembly **800** comprises a busbar **802** housed within a sealed housing **804**. Also as above, the housing **804** is pressurized with SF₆ gas. However, in this embodiment, an input electrical power cable **806** is connected directly to the busbar **802**, rather than to a supply-side circuit breaker, such as circuit breaker **57** in FIG. 2. The cable **806** extends through a sealed penetration **808** in the housing **804**. The end of the cable **806** opposite the busbar **802** is connected to an electrical connector **810**. Circuit breaker assemblies may be connected to the busbar **802** to couple power from the busbar **802** to electrical loads. Alternatively, additional electrical cables **806** may be connected directly to the busbar **802** and routed to supply electrical loads. The busbar housing **804**, cable **806**, cable electrical connector **810**, etc., are supported by a frame **812**.

[0073] As noted above, one or more specific embodiments of the present invention were provided above. In an effort to provide a concise description of these embodiments, not all features of an actual implementation were described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers’ specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill in the art and having the benefit of this disclosure.

What is claimed is:

1. A subsea electrical distribution system, comprising:
 - a first subsea circuit breaker module comprising a first busbar and a first plurality of circuit breakers electrically coupled to the first busbar; and
 - a second subsea circuit breaker module comprising a second busbar and a second plurality of circuit breakers connected to the second busbar, wherein the second

busbar is electrically coupled to the first busbar of the first subsea circuit breaker module.

2. The subsea electrical distribution system of claim 1, comprising a first subsea circuit breaker control module disposed in an enclosure separate from the first circuit breaker module, wherein the first subsea circuit breaker control module is in communication with the first subsea circuit breaker module, the first subsea circuit breaker control module being operable to control opening and closing of the plurality of circuit breakers within the first subsea circuit breaker module.

3. The subsea electrical distribution system of claim 2, wherein at least one circuit breaker of the first plurality of circuit breakers comprises a closing coil and a trip coil, each of the closing coil and the trip coil being controlled by the first subsea circuit breaker control module.

4. The subsea electrical distribution system of claim 2, wherein the first subsea circuit breaker module is in communication with a surface location via a fiber optic communication link.

5. The subsea electrical distribution system of claim 1, wherein the second busbar is electrically coupled to the first busbar through a first circuit breaker in the first plurality of circuit breakers.

6. The subsea electrical distribution system of claim 5, wherein the second busbar is electrically coupled to the first busbar through a first circuit breaker in the second plurality of circuit breakers.

7. The subsea electrical distribution system of claim 1, comprising a third subsea circuit breaker module comprising a third busbar and a third plurality of circuit breakers connected to the third busbar, wherein the third busbar is electrically coupled to the first busbar of the first subsea circuit breaker module.

8. The subsea electrical distribution system of claim 7, wherein the third busbar is electrically coupled to the first busbar through a second circuit breaker in the first plurality of circuit breakers.

9. A modular subsea circuit breaker assembly, comprising:
a busbar enclosure having a hollow interior housing a busbar, wherein the busbar enclosure comprises a plurality of flanged connections; and
a plurality of circuit breaker enclosures, each of the plurality of circuit breaker enclosures having a hollow interior housing a circuit breaker electrically coupled to the busbar, wherein each circuit breaker enclosure comprises a flanged connection securable to a flanged connection of the busbar enclosure.

10. The modular subsea circuit breaker assembly of claim 9, wherein each circuit breaker is electrically coupled to the busbar by extending a conductor through a sealed opening between the busbar enclosure and the circuit breaker enclosure of the circuit breaker.

11. The modular subsea circuit breaker assembly of claim 10, wherein the quantity of circuit breaker enclosures in the plurality of circuit breaker enclosures is less than the quantity of flanged connections in the plurality of flanged connections of the busbar enclosure, further wherein a cover is disposed over any flanged connections of the busbar enclosure that are not used to secure a circuit breaker enclosure to the busbar enclosure.

12. The modular subsea circuit breaker assembly of claim 9, wherein each of the plurality of flanged connections of the

busbar enclosure are oriented so that each of the plurality of circuit breaker enclosures is oriented transverse to the busbar.

13. The modular subsea circuit breaker assembly of claim 12, wherein at least two of the plurality of flanged connections of the busbar enclosure are oriented on opposite sides of the busbar enclosure.

14. The modular subsea circuit breaker assembly of claim 9, comprising a control module operable to control opening and closing of at least one of the plurality of circuit breakers, wherein the control module is housed in an enclosure separate from the busbar enclosure and each of the plurality of circuit breaker enclosures.

15. A method for assembling a subsea electrical distribution system, comprising:

identifying a quantity of circuit breakers desired in a subsea circuit breaker assembly;

securing the quantity of modular subsea circuit breaker assemblies to a modular busbar enclosure having a busbar and a plurality of connectors configured to receive a modular subsea circuit breaker assembly; and
sealing any connectors on the modular busbar enclosure to which a modular subsea circuit breaker assembly is not secured.

16. The method of claim 15, comprising:
coupling a circuit breaker within a circuit breaker assembly to the busbar in the busbar enclosure; and
sealing the busbar enclosure from the circuit breaker assembly.

17. The method of claim 15, comprising:
securing the modular busbar and the plurality of circuit breaker assemblies to a frame having a plurality of electrical connectors secured thereto;
connecting a first end of a subsea power cable to a subsea circuit breaker assembly; and
connecting an opposite end of the subsea power cable to an electrical connector secured to the frame.

18. A method for assembling a subsea electrical distribution system, comprising:

identifying a quantity of circuit breakers desired in a subsea circuit breaker assembly;

providing a quantity of modular subsea circuit breaker assemblies comprising a quantity of circuit breakers equal to the quantity of circuit breakers desired in the subsea circuit breaker assembly, each modular subsea circuit breaker assembly having a flanged connector; and

securing the quantity of modular subsea circuit breaker assemblies to a modular busbar enclosure having a busbar and plurality of flanged connectors configured to receive a flanged connector of a modular subsea circuit breaker assembly.

19. The method of claim 18, comprising:
securing a cover to a flanged connector of the busbar enclosure not having a modular subsea circuit breaker assembly secured thereto.

20. The method of claim 18, comprising:
coupling a circuit breaker within a modular circuit breaker assembly to the busbar in the busbar enclosure; and
sealing the modular busbar enclosure from the modular circuit breaker assembly.