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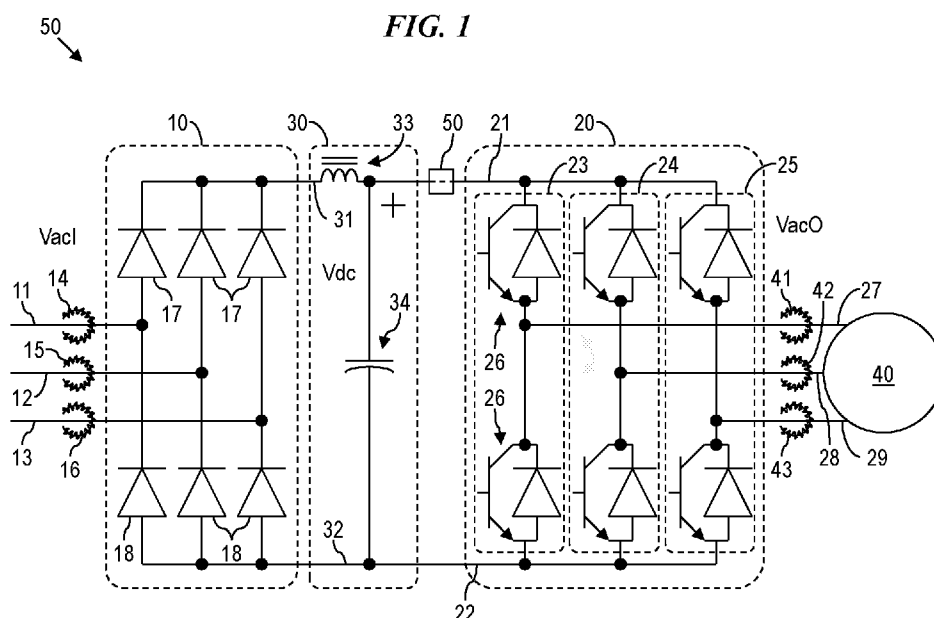
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(54) Title: INTEGRATED POWER AND ELECTRONICS UNIT FOR DRILLING MACHINE



(57) **Abstract:** An integrated power and electronics unit (IPEU) operable for providing output power for driving an electric motor of a drilling rig machine. The IPEU comprises a housing, a radiator, and a VFD. The radiator is mounted within the housing and comprises radiating members each extending through an opening in the housing. The VFD comprises insulated-gate bipolar transistor devices (IGBTs) operable to convert input power to the output power. The IGBTs are coupled to the radiator within the housing such that heat generated by the IGBTs is transferred out of the housing via the radiator. The VFD also comprises a controller operable to control the IGBTs.

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Integrated Power and Electronics Unit for Drilling Machine

Cross-Reference to Related Applications

[0001] This application claims priority to and the benefit of U.S. Provisional Application No. 62/491,689, titled “Integrated Power and Electronics Unit for Drilling Machine,” filed April 28, 2017, the entire disclosure of which is hereby incorporated herein by reference.

Background of the Disclosure

[0002] On an alternating-current (AC) drilling rig, an AC generator set generates the electrical power used to operate the heavy rig equipment, such as the top drive, the mud pump, and the drawworks. The AC generator set includes an AC generator powered by a diesel engine or other prime mover. The resulting AC current is utilized by a variable-frequency drive (VFD) associated with the rig equipment component, such that the top drive, mud pump, and drawworks may each have a dedicated VFD.

[0003] The VFDs may be installed in an access-controlled room, known as a power house, a power-control room (PCR), a local electronics room (LER), and the like. While the VFDs are primarily utilized to power the main rig machines (the top drive, the mud pump, and the drawworks), smaller motors installed on or otherwise associated with the main machines (and/or perhaps other “non-main” rig equipment) may be also operated from the power house, such as cooling fans, centrifugal pumps (such as for feeding mud pumps), lubrication systems, and other examples.

Summary of the Disclosure

[0004] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify indispensable features of the claimed subject matter, nor is it intended for use as an aid in limiting the scope of the claimed subject matter.

[0005] The present disclosure introduces an apparatus including an IPEU operable for providing output power for driving an electric motor of a drilling rig machine. The IPEU includes a housing, a radiator, and a VFD. The radiator is mounted within the housing and includes radiating members each extending through an opening in the housing. The VFD includes insulated-gate bipolar transistor (IGBT) devices operable to convert input power to the

output power. The IGBTs are coupled to the radiator within the housing such that heat generated by the IGBTs is transferred out of the housing via the radiator. The VFD also includes a controller operable to control the IGBTs.

[0006] The present disclosure also introduces an apparatus including a drilling rig machine and an IPEU operable for providing output power for driving an electric motor of the drilling rig machine. The IPEU includes a housing, a radiator, and a VFD. The radiator is mounted within the housing and includes radiating members each extending through an opening in the housing. The VFD includes IGBTs operable to convert input power to the output power. The IGBTs are coupled to the radiator within the housing such that heat generated by the IGBTs is transferred out of the housing via the radiator. The VFD also includes a controller operable to control the IGBTs.

[0007] These and additional aspects of the present disclosure are set forth in the description that follows, and/or may be learned by a person having ordinary skill in the art by reading the material herein and/or practicing the principles described herein. At least some aspects of the present disclosure may be achieved via means recited in the attached claims.

Brief Description of the Drawings

[0008] The present disclosure is understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0009] FIG. 1 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0010] FIG. 2 is a graph depicting one or more aspects pertaining to the present disclosure.

[0011] FIG. 3 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0012] FIG. 4 is a perspective view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0013] FIG. 5 is a front view of at least a portion of an example implementation of the apparatus shown in FIG. 4 according to one or more aspects of the present disclosure.

[0014] FIG. 6 is a top view of at least a portion of an example implementation of the apparatus shown in FIG. 5 according to one or more aspects of the present disclosure.

[0015] FIG. 7 is a perspective view of at least a portion of another example implementation of the apparatus shown in FIG. 4 according to one or more aspects of the present disclosure.

[0016] FIG. 8 is a top view of a portion of the apparatus shown in FIG. 7 according to one or more aspects of the present disclosure.

[0017] FIG. 9 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0018] FIG. 10 is a top view of a portion of an example implementation of the apparatus shown in FIG. 9 according to one or more aspects of the present disclosure.

[0019] FIG. 11 is a schematic view of at least a portion of another example implementation of the apparatus shown in FIG. 9 according to one or more aspects of the present disclosure.

[0020] FIG. 12 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0021] FIG. 13 is a sectional view of the apparatus shown in FIG. 12.

[0022] FIG. 14 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0023] FIG. 15 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0024] FIG. 16 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0025] FIG. 17 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0026] FIG. 18 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0027] FIG. 19 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0028] FIG. 20 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

[0029] FIG. 21 is a schematic view of at least a portion of an example implementation of apparatus according to one or more aspects of the present disclosure.

Detailed Description

[0030] It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of various embodiments. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for simplicity and clarity, and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

[0031] FIG. 1 is a schematic view of an example implementation of a VFD 50 for driving an induction motor within the scope of the present disclosure. The VFD 50 includes a rectifier circuit 10, an inverter circuit 20, and perhaps a filter circuit 30.

[0032] The rectifier circuit 10 rectifies three-phase input power (V_{acI}) from three inputs 11, 12, 13 (measurable via, for example, respective current probes and/or other measurement means 14, 15, 16) to generate DC power (*e.g.*, with limited undulation). In the example implementation depicted in FIG. 1, each input 11, 12, 13 is connected between an anode of a corresponding first diode 17 and a cathode of a corresponding second diode 18. The cathodes of the first diodes 17 are connected to a positive lead 31 of the filter circuit 30, and the anodes of the second diodes 18 are connected to a negative lead 32 of the filter circuit 30.

[0033] The filter circuit 30 may be or comprise an LC (inductor-capacitor) circuit and/or other means for reducing noise generated by the rectifier circuit 10, thus smoothing the direct current voltage (V_{dc}) fed to the inverter circuit 20. In the example implementation depicted in FIG. 1, the filter circuit 30 includes an inductor (*e.g.*, solenoid) 33 connected in series between the positive lead 31 of the filter circuit 30 and a positive lead 21 of the inverter circuit 20, and a capacitor 34 connected between the positive and negative leads 31, 32 of the filter circuit 30. However, other implementations of the filter circuit 30 are also within the scope of the present disclosure.

[0034] The inverter circuit 20 produces, for delivery to inputs 27, 28, 29 of the motor 40, the three-phase output V_{acO} (measurable via, for example, respective current probes and/or other measurement means 41, 42, 43) at the frequency and amplitude intended to drive the motor 40. In the example implementation depicted in FIG. 1, the inverter circuit 20 includes three single-phase inverter switches 23, 24, 25 that each include first and second inverters 26. The inverters 26 are depicted in FIG. 1 as simple transistor switches, but various other devices may be utilized

for the inverters 26, including IGBT devices. The motor input 27 is connected between the first and second inverters 26 of the switch 23, the motor input 28 is connected between the first and second inverters 26 of the switch 24, and the motor input 29 is connected between the first and second inverters 26 of the switch 25. However, other implementations of the inverter circuit 20 are also within the scope of the present disclosure.

[0035] The VacO generated by the inverter circuit 20 may range between about 5 Hertz (Hz) and about 100 Hz, although perhaps as high as 300 Hz. The measurement means 14-16 associated with the inputs 11-13, the measurement means 41-43 associated with the motor inputs 27-29, and perhaps one or more other sensors (*e.g.*, sensor 50 connected between the filter circuit 30 and the inverter circuit 20) are examples of sensors that may be utilized to monitor and perhaps provide automatic or manual feedback for operation of the motor 40. These and/or other current, voltage, and/or frequency sensors (or other measurement means) may aid in managing the VFD 50 and other power electronics in relation with demand.

[0036] FIG. 2 depicts an example pulse-width modulation (PWM) 60 that may be used to provide the three-phase output VacO at the intended frequency and amplitude to drive the motor 40 at a target speed. The driving signal intended to be delivered to the motor input 27 is represented by sine wave 61, and is generated by the PWM signal 62 via operation of the switch 23. Similarly, the driving signal intended to be delivered to the motor input 28 is represented by sine wave 63, which is generated by the PWM signal 64 via operation of the switch 24, and the driving signal intended to be delivered to the motor input 29 is represented by sine wave 65, which is generated by the PWM signal 66 via operation of the switch 25. Each intended driving signal 61, 63, 65 is compared with a reference triangle wave and/or other waveform 67. When the reference waveform 67 is less than the intended driving signal 61, 63, 65, the corresponding PWM signal 62, 64, 66 is at “high” state (*e.g.*, 1), and when the reference waveform 67 is greater than the intended driving signal 61, 63, 65, the corresponding PWM signal 62, 64, 66 is at “low” state (*e.g.*, 0).

[0037] The present disclosure introduces an integrated power and electronics unit (IPEU) that is integrated in a drilling rig machine skid, such as a mud pump skid, a drawworks skid, and others. The IPEU alone delivers the electrical and control support for the equipment on that skid. For example, the IPEU includes a VFD for the main motor of the primary machine of the skid (*e.g.*, mud pump, drawworks, top drive, *etc.*), a controller, and a networking interface. The IPEU may also include a VFD and starter(s) for one or more motors of secondary machines/functions,

such as cooling blowers, centrifugal pumps, lubricating pumps, and other examples. The IPEU may also include means for data acquisition, such as from sensors associated with equipment on the skid, from equipment not integrated in the skid (such as the main controller of the drilling rig via the networking interface), and/or from mobile electronic devices (*e.g.*, tablet computers, smartphones, laptop computers, *etc.*) proximate the IPEU. The IPEU may also include emergency stop means for abruptly halting operation of one or more components of the skid.

[0038] The IPEU receives electrical power from a power source at the wellsite via a power cable. Information exchanged between the IPEU and equipment not integrated in the skid (both to and from the IPEU) may be via a cable and/or wireless communication. The IPEU may also share information for coordination between multiple machines on the skid, such as in implementations in which the mud pump system includes multiple pumps that, via the information sharing, operate out of phase with respect to each other so as to reduce vibration and/or to achieve a more continuous output flow.

[0039] The IPEU and the main motor of the skid (including the related electronics for power and control) may be a single, integrated component, such as may be sold or marketed as a single product, in contrast to an assembly of separately marketed components. The IPEU and the main motor may also be an integrated component of a fully integrated skid. The integrated IPEU/motor/electronics product may be operable to perform for a predefined period of time with no (or very limited) maintenance. Moreover, the electronics and perhaps other portions of the integrated product may not be accessible by the end user, such that installation of the integrated product by the end user may be limited to connecting and disconnecting the power and communication cables, until the integrated product reaches the end of operational life and is replaced by a new or refurbished (OEM) unit.

[0040] Aspects of the IPEU may include: compact and low weight unit; integrated heat transfer from VFD power switches, including for dirty airflow; management of motor braking period; management of outdoor thermal and radiation conditions to maintain internal temperature within predetermined ranges; management of internal humidity; packaging that aids in preventing damage from vibration and shocks during handling, transport, and operation; and/or easy rig-up (*e.g.*, simplified cable connection).

[0041] The IPEU may operate without usage of AC cooling or water flow utilized to transfer the heat generated by the VFD power switches to the outside the unit. The IPEU housing may contain the VFD (or part of the VFD), an associated programmable logic controller (PLC) and/or

other controller, sensors and/or other means for measurement of conditions and operating parameters internal to the housing, and perhaps one or more filter components. The IPEU electronics may control a motor having a power rating above 100 horsepower (HP), perhaps higher than 1,000 HP, or even above 2,500 HP. The IPEU electronics may also control two or more such motors collectively, and may also control a resistor brake system. The IPEU is powered by a power source, which may be a single cable, and may be controlled via cable connection (*e.g.*, metal and/or fiber-optic) and/or wireless communications.

[0042] The IPEU may be utilized for various traction motors of a drilling rig, such as motors of triplex and/or other pumping systems, drawworks systems, and top drives, among other examples. The IPEU may also be utilized for smaller motors on the rig, such as for a transfer pump, perhaps concurrently with the traction motors. Such implementations may be for fracturing pumping systems, such as may comprise one or more electrically driven triplex pumps, as well as low-pressure side components of a fracturing system, such as electrically driven centrifugal pumps, conveyor belts, mixers, agitators, and the like.

[0043] The IPEU may be mounted on the skid of a machine being powered by the VFD and perhaps controlled by the IPEU. The IPEU may also be mounted directly on the motor of such machine.

[0044] FIG. 3 is a schematic view of at least a portion of an example implementation of an IPEU 100 according to one or more aspects of the present disclosure. The IPEU 100 includes a housing (*e.g.*, a rectangular metal box) 105. An input power bulkhead connector 110 for receiving electrical power from a power source 101, one or more communication bulkhead connectors 115 for receiving data and/or control signals from one or more data and/or control sources 116, an output power bulkhead connector 120 leading to one or more main motors 102 driven by the IPEU 100, a primary radiator 125, and perhaps a secondary radiator 130 each extend through openings in the housing 105. The housing 105 may have an access door (not shown) for assembly/maintenance purposes.

[0045] The IPEU 100 includes a VFD implemented via three insulated-gate bipolar transistor (IGBT) devices 135, although another number of IGBT devices 135 may be used. The IPEU 100 also includes a primary radiator 125 comprising a plate 126 secured to the housing 105 via bolts and/or other attachment means 140. The primary radiator 125 also includes fins and/or other elongated radiating members 127 extending from the plate 126 and through an opening in the housing 105, thus extending externally from the housing 105. The IGBT devices 135 are

secured to the plate 126 (opposite the radiating members 127) in a manner permitting heat transfer (via conduction and/or otherwise) from the IGBTs 135 to the radiating members 127.

[0046] The IPEU 100 also includes a controller 145, which may be or comprise a programmable logic controller operable to control the IGBTs 135. However, the controller 145 may also be operable to control other components of the IPEU 100, and perhaps components of a skid (not shown) comprising the IPEU 100, in addition to the IPEU. The controller 145 may include a communications interface 146 permitting communication between the controller 145 and other components of the IPEU 100. The communications interface 146 may also permit communication between the controller 145 and components not included in the IPEU 100, such as other components on the skid, and perhaps other components not located on the skid. Such communication, whether internal to the IPEU 100, internal to the skid, or external to the skid, may be via wired connection and/or via wireless communication (*e.g.*, via antenna/receiver 147).

[0047] The IPEU 100 may also include one or more fans 150 operable to increase airflow across the radiating members 127. In the example implementation depicted in FIG. 3, the airflow is perpendicular to the page. Ducting 128 attached to the housing 105 may also be included to focus airflow across the radiating members 127. The fans 150 may include electric motors 151 energized by a secondary VFD 155 also contained within the housing 105. Control of the fans 150 may be via the secondary VFD 155 and/or the controller 145.

[0048] The primary radiator 125 (and perhaps the fans 150) may be configured to sufficiently manage the heat generated by the IGBTs 135. However, the controller 145, the secondary VFD 155, and/or other internal components of the IPEU 100 may generate additional heat not sufficiently managed by the primary radiator 125 (and perhaps the fans 150). Thus, the IPEU 100 may also include a secondary radiator 130 and/or a secondary fan 165 internal to the housing 105 (although two or more of the secondary radiator 130 and/or the secondary fan 165 may be included).

[0049] A plate 131 of the secondary radiator 130 may be secured to the housing 105 via bolts and/or other attachment means 141. The secondary radiator 130 may include internal fins and/or other elongated members 132 extending internally from the plate 131 within the housing 105, and external fins and/or other elongated radiating members 133 extending from the plate 131 and through an opening in the housing 105, thus extending externally from the housing 105 (opposite the internal members 132).

[0050] The fan 165 may be operable to increase airflow 160 across the internal elongated members 132 of the secondary radiator 130. The fan 165 may include an electric motor 166 energized by the secondary VFD 155. Control of the fan 165 may be via the secondary VFD 155 and/or the controller 145. The fan 165 may circulate air inside the IPEU 100 for improved heat transfer from the various components generating heat (such as the controller 145) to the external environment. Such heat transfer may be from the internal air to the secondary radiator 130 by convection, through the secondary radiator 130 by conduction, and/or to the outside air by convection, perhaps simultaneously. However, the IPEU 100 may be sealed to protect against rain, water splash, *etc.*, such that there may be no exchange of air between the inside of the IPEU 100 and the external environment.

[0051] As described above, IGBTs 135 are the main source of heat within the IPEU 100, and such heat is evacuated by the airflow across the radiating members 127. Other components of the IPEU 100 generate smaller amounts of heat (controller 145, sensors, *etc.*). Heat may be evacuated from these components by the internal fan 165 and transmitted outside the IPEU 100 through the wall of the housing 105 (conduction through the wall and convection on both sides of the wall), and/or via the secondary radiator 130. However, it may be critical to control this heat flow.

[0052] For example, such control can be achieved by controlling the speed of the internal fan 165 while ensuring no overheating of local elements. However, the IPEU 100 may be operating in a low-temperature environment. In such conditions, the housing 105 provides some thermal isolation, and the heat flow from the secondary heat sources (i.e., components other than the IGBTs 135) may be transmitted to the surrounding air by the housing 105 itself, or in conjunction with the secondary radiator 130. In some cases, one or more external fans 134 (such as with electric motors 136) may be added to create forced convection against the radiating members 133. The radiating members 133 may be inside a duct 137 with openings on both extremities to allow outside air to circulate. In extreme cold weather, the ends of the duct 137 may be closed to reduce heat transfer by the secondary radiator 130. Such an implementation permits full control of heat exchange, thus permitting operating over a wider range of temperature.

[0053] The IPEU 100 may also be protected against heat transfer by radiation. For example, a radiation shield 138 may be used to avoid overheating of the electronics of the IPEU 100 when operating in a sunny location (*e.g.*, a desert). The radiation shield 138 may also aid in avoiding

too much cooling when operating during cold, clear weather nights, when radiation towards the cold black sky could otherwise be excessive. The radiation shield 138 may be or comprise a roof or other structure above the housing 105, such as may be supported by structural members 139 attached to the housing 105 and/or other structure near the IPEU 100. However, the radiation shield 138 may also or instead be or comprise a layer of additional thermal insulation inside and/or outside the housing 105, and/or a highly reflective surface (silver, mirror, white, *etc.*) inside and/or outside the housing 105, among other examples.

[0054] The IPEU 100 may also include various sensors operable for detecting temperature, pressure, humidity, airflow, and/or other parameters of the IPEU 100. In the example implementation depicted in FIG. 3, such sensors include a temperature sensor 170 for detecting the temperature of the plate 126, and a temperature sensor 171 for detecting the temperature of the airflow in the ducting 128. However, other sensors may also be included. The sensors may generate signals indicative of the sensed parameters, and the controller 145 may be operable to receive the signals (via wired or wireless connections) for use in operation of the IGBTs 135, the fans 150, the fan 165, and/or other components, for example.

[0055] FIG. 4 is a schematic view of an example implementation of the radiator 125, designated in FIG. 4 by reference number 200. The filter 200 includes a filter 210 for blocking particles 220 that, when carried by air flow 202, would be large enough to clog the radiating members 127. Such particles 220 are redirected by the filter 200 along an alternate path 204 above the radiating members 127. However, the filter 210 otherwise permits passage of the air flow 202, and perhaps smaller particles 222 that are small enough to pass through the radiating members 127.

[0056] FIGS. 5 and 6 are front and top views of the radiator 200 without the filter 210. Referring to FIGS. 3-6, collectively, the radiating members 127 may each be a cylinder 230 made from copper and/or other materials having high thermal conductivity. Each cylinder 230 extends perpendicular from the base plate 126 that supports the IGBT devices 135. The ratio of diameter to length of each radiating member 127 may be optimized to ensure proper heat flux far from the base plate 126. As also shown in FIGS. 4-6, each radiating member 127 may be equipped with radial extensions (wings) 232 also made of copper and/or other materials having high thermal conductivity, such as may increase the surface area in contact with the air flow 202. The radial extensions 232 of neighboring radiating members 127 may be interlaced (as depicted in FIG. 5), and neighboring rows of radiating members 127 in the array may be staggered (as

depicted in FIG. 6), each or both of which may encourage turbulence and/or other flow disruption that increases the area and/or time of contact between the radiating members 127 and the air flow 202, thereby increasing convection and/or other transfer of heat from the radiating members 127 to the air flow 202.

[0057] The filter 210 may be inclined at an angle 206 (between parallel and perpendicular relative to the direction of the air flow 202) relative to the base plate 126, as depicted in FIG. 4, so that particles 220 too large to pass between the radiating members 127 can be deflected past the filter 210 (*e.g.*, along the alternate path 204). Another filter (not shown) similar to the inclined filter 210 may also extend from the inclined filter 210 over the radiating members 127, such as parallel with the base plate 126, to prevent the particles 220 deflected by the inclined filter 210 from dropping back down into the array of radiating members 127. The filter(s) may be positioned before and/or after (relative to the direction of air flow) the fans 150 that establish the air flow 202 into the array of radiating members 127.

[0058] FIG. 7 is a schematic view of another implementation of the radiator 125 shown in FIG. 3, designated in FIG. 7 by reference number 250. The radiator 250 includes radiating members 252 resembling blades extending parallel to the direction of the air flow 202 caused by the fan(s) 150. FIG. 8 is a top view of two of the radiating members 252, a large particle 220 deflected by leading edges 254 of the radiating members 252, and a smaller particle 220 traveling between the radiating members 252. The leading edge 254 of each radiating member 252 is inclined at an angle 256 (between parallel and perpendicular relative to the direction of the air flow 202) relative to the base plate 126. The leading edge 254 may also be broader than the body 258 of the radiating member 252, so that particles 220 roll along the broader leading edge 254 and then along an alternate path 205 over the radiating members 252 if they are too large to pass between the narrow gaps between the leading edges 254. Furthermore, because the leading edges 254 are thicker than the bodies 258, particles 222 that are small enough to enter between the leading edges 254 are able to move freely with the air flow 202 through the radiator 250. Although not depicted in FIGS. 7 and 8, the top edges 260 of the radiating members 252 may also be broader than the bodies 228, like the leading edges 254, so that larger particles 220 deflected by the leading edges 254 cannot fall between the bodies 258 and get lodged.

[0059] The radiating members 127, 252 depicted in FIGS. 4-8 are made of a material with high thermal conductivity, such as copper, aluminum, and/or other metals. The material may also be incrustated with PCD (polycrystalline diamond) and/or other materials to increase thermal

conductivity and wear resistance, as well as reducing the mean thermal expansion coefficient. The radial extensions 232 shown in FIGS. 4-6 and/or the leading edges 254 shown in FIGS. 7 and 8, for example, may be of (or coated with) PCD. Such extensions/edges, however, may not be of a specific determined shape, contrary to the depictions in FIGS. 4-8.

[0060] The filters described above, and/or an additional filter added near one or more of the fans, may aid in ensuring that the outside air is sufficiently clean to avoid creation of a dust/dirt layer on the external surfaces of the radiator. Such designs may reduce or eliminate sand, proppant dust, water droplets, *etc.*, and may introduce a series of changes in air flow so that these particles fall to the ground. Such designs may reduce or eliminate mud droplets, such as when operating in the vicinity of mud splash, although a longer air supply chimney may be used to move the air supply entrance further away from the potential mud splash source. To eliminate large/longer components, such as fiber, flake, leaves, paper, *etc.*, a hydrocyclone may be used, although the radiator/filter designs described above may sufficiently perform this function.

[0061] FIG. 9 is a schematic view of a portion of another implementation of the IPEU 100 shown in FIG. 3, designated in FIG. 9 by reference number 300. The IPEU 300 shown in FIG. 9 is substantially the same as the IPEU 100 shown in FIG. 3, except as described below. FIG. 10 is a sectional view of a portion of the IPEU 300. The following description refers to FIGS. 9 and 10, collectively, as well as to FIG. 3 where indicated by like reference numbers.

[0062] The IPEU 300 includes a chimney 302 that guides the cooling air flow 202 from the exterior of the housing 105 through the IPEU 300 via operation of a fan 310 and associated motor 311. The base plates 126 supporting the IGBTs 135 are attached to the exterior of the chimney 302 or otherwise positioned such that the radiating members 127 extend into the interior of the chimney 302. Thus, the fan 310 forces external air through the chimney 302, including across the radiating members 127. This arrangement may permit more room for elements inside the housing 105 and/or aid in ensuring adequate cooling, relative to the arrangement shown in FIG. 3. One or more instances of the fan 310 may push or pull the air flow 202 through the chimney 302.

[0063] The chimney 302 may also have a self-orienting exit guide that rotates depending on the direction of wind external to the IPEU 300, such as to ensure that the exhaust is directed downwind from the entry 304. For example, an exhaust tube 308 may be pivotably attached to the housing 105 at the exit 306, such that wind spins the exhaust tube 308 toward a downwind

direction. One or more vanes and/or other means 309 may be attached to the exhaust tube 308 to provide more sensitivity to the wind.

[0064] The chimney 302 may have a rectangular cross-section, as shown in FIG. 10. However, the entry 304 and exit 306 of the chimney 302 may be shaped to improve airflow via natural convection. For example, the entry 304 and/or the exit 306 may have a convergent shape, a divergent shape, or perhaps a paraboloid-hyperbolic shape as depicted in FIG. 11. FIG. 11 also depicts that the air flow 202 may be in a direction opposite gravity.

[0065] FIGS. 12 and 13 are respective schematic top and side views of an example implementation of the primary radiator 125, designated in FIGS. 12 and 13 by reference number 350. The primary radiator 350 depicted in FIGS. 12 and 13 is an example for how each IGBT 135 may operate at substantially the same temperature as a result of the design of the base plate 352 and the radiating members 354. The base plate 352 and the radiating members 354 are substantially the same as the base plate 126 and the radiating members 127 shown in FIG. 3, except that the radiating members 354 get progressively longer from the leading edge 356 to the trailing edge 358 of the base plate 352, and the base plate 352 gets progressively thicker from the leading edge 356 to the trailing edge 358. The thickness of the base plate 352 is in the vertical direction in FIG. 13. The packing density of the radiating members 354 may also get progressively larger from the leading edge 356 to the trailing edge 358. For example, each row 355 of the radiating members 354 may be closer to the downwind neighboring row 355 (on the trailing edge 358 side) than to the upwind neighboring row 355 (on the leading edge 356 side). The example implementation depicted in FIG. 12 includes fifteen rows 355 of radiating members 354 (seven of which are labeled), but implementations having another number of rows 355 are also within the scope of the present disclosure.

[0066] This may avoid overheating of some IGBTs 135, while ensuring that their “speed” response is similar for proper sharing of current during PWM switching. That is, the air flow 202 increases in temperature as it travels through the radiating members. Consequently, if the primary radiator 125 shown in FIG. 3 is utilized, a thermal gradient may be established in the IGBTs 135, with the end of each IGBT 135 that is nearest the leading edge being cooler than the opposite end of the IGBT 135 that is furthest from the leading edge, because the radiating members 127 nearest the leading edge dissipate more heat to the air due to the greater temperature difference relative to the temperature of the air flow 202. However, with the primary radiator 350 depicted in FIGS. 12 and 13, the thickness of the baseplate 352 and the

length and/or packing of the radiating members 354 increases along a direction from the leading edge 356 to the trailing edge 358. This may permit more even cooling of the IGBTs 135 attached to the baseplate 352. For example, the increasing thickness of the baseplate 352 may permit more heat conduction away from the IGBTs 135, and the increasing length and/or packing of the radiating members 354 may permit more heat convection to the air flow 202.

[0067] Additional cooling methods to evacuate heat may also or instead be utilized. For example, when the IPEU is associated with the motor of a pump 180 (triplex, centrifugal, *etc.*), the baseplate 126/352 may be in contact with the pumped fluid. The cooling liquid may be the fluid being pumped by the driven pump (*e.g.*, drilling mud). The baseplate may be optimized to avoid damage or clogging by particles and chemicals in the pumped fluid, such as lost-circulation material (LCM), fiber, flakes, or even limited size drill-cuttings when associated with a return-mud transfer centrifugal pump. For such implementations, the radiating members 127, 132, 354 may also or instead be in contact with the pumped fluid, and may be properly profiled so as to not entirely cut the whole fluid flow, thus permitting the particles and flakes to be evacuated by the flow. The fluid velocity may be relatively high to increase the forced convection. Protective material (boronized metal, PCD, *etc.*) may cover surfaces of the radiating members and/or baseplate that are contacted by the fluid, such as to limit erosion.

[0068] In a related implementation also depicted in FIG. 13, a nozzle 360 may spray water 361 toward and/or on the radiating members 354. This may increase the heat removal. This may be convenient when the associated motor rarely operates a full load, such as may be true for the top drive which may be operated mostly at 50% (or less) of its power limit.

[0069] In a related implementation also depicted in FIG. 13, a nozzle 362 may direct compressed air toward the radiating members 354. This may ensure high velocity of air through the radiating members 354, which may improve forced convection. Also, the sudden reduction of pressure in the air nozzle 362 may create a cooling effect for the air, which may also help the forced convection because the temperature difference between the air and the radiating members 354 is increased.

[0070] When several IPEUs are installed in a limited space (such as for multiple triplex pump systems, drawworks, *etc.*), among other implementations, the IGBTs 135 may be cooled as a conventional water-cooled VFD. The cooling fluid (water) for these multiple VFDs may be cooled by a conventional radiator associated with the skid/trailer construction, such as for a large trailer with three triplex systems. In the example implementation depicted in FIG. 13, a pump

370 (*e.g.*, driven by a motor 372) pumps cooling fluid (*e.g.*, water) 374 through channels 376 in the base plate 356 via various tubing and/or other conduits 378. The heat carried from the base plate 356 by the cooling fluid 374 may dissipate in a collection tank 380 and/or via a radiator 382. In other implementations, another radiator associated with the skid/trailer and/or otherwise may also or instead be utilized.

[0071] FIG. 14 is a schematic view of at least a portion of another implementation of the example shown in FIG. 9. The IPEU may also be optimized to reduce problems generated by internal condensation during cooling periods. As depicted in FIG. 14, this may entail the usage of silica gel desiccant that absorbs the humidity of the air contained in the housing 105.

However, with time, the silica gel becomes saturated and may no longer absorb water. In such case, the silica gel may be changed and replaced by “dried” silica gel. The detection of saturation may be via a sensor, such as may detect the color of the silica gel if the silica is of the type that is one color (blue) when dry but another color (pink or reddish) when saturated. For example, in FIG. 14, the silica gel 402 in a first container 404 is saturated, while the silica gel 406 in a second container 408 is dry.

[0072] This process may also be automated. For example, as shown in FIG. 14, the second container 408 is connected to the inside of the IPEU when an internal door 410 is open to the inside of the IPEU. A mesh, grid, or other barrier 412 permits air communication between the silica gel 406 and the inside of the IPEU, but prevents the silica gel 406 from escaping the container 408. The other container 404 is connected to the chimney 302 when an external door 420 is open to the chimney 302. A mesh, grid, or other barrier 422 permits air communication between the silica gel 402 and the chimney 302, but prevents the silica gel 402 from escaping the container 404. Both containers 404, 408 are equipped with the internal and external doors 410, 420, which are opened and closed by corresponding actuators 414, 424. The controller 145 monitors the temperature in the chimney (*e.g.*, via a temperature sensor 416), the temperature inside the IPEU (*e.g.*, via a temperature sensor 418), and color of both silica gels 402, 406. The internal doors 410 may generally remain open. However, when one of the silica gels 402, 406 becomes saturated (or even before then), and the air flow 202 in the chimney 302 exceeds a predetermined temperature, the controller 145 may open the external door 420 of the container 404, 408 having the saturated silica gel, such that the hot air of the chimney 302 may be utilized to dry the saturated silica gel. When the silica gel of the container connected to the chimney 302 reaches the “dry” status (*e.g.*, based on color), the controller 145 may inverse the doors of that

silica gel container. Performing the door position swapping may be limited to when the fan 311 is stopped.

[0073] FIG. 15 is a schematic view of another example implementation of the VFD 50 of FIG. 1, designated in FIG. 15 by reference number 450. The VFD 450 depicted FIG. 15 is the same as the VFD 50 depicted in FIG. 1 except as described below. Elements depicted in FIG. 1 but not in FIG. 15 may nonetheless exist in the VFD 450. The inverters 26 are depicted in FIG. 15 as IGBTs, such as the IGBTs 135 described above, with the gate of each IGBT 26 connected to a logic controller 452, such as the controller 145 described above.

[0074] The DC bus 21 may be connected to a chopper 454 to allow braking effect of the motor 40. The chopper 454 is depicted in FIG. 15 as another IGBT, but other means may instead or additionally be utilized to implement the chopper 454 within the scope of the present disclosure.

[0075] When the induction motor 40 is acting as a generator while the inverter circuit 21 is driven at proper AC frequency, the diodes of the IGBTs 26 may act as rectifiers, such that AC voltage generated by the induction motor 40 is rectified and may raise the DC voltage. The chopper 454 may evacuate some of this DC power into a brake resistor 456. Such resistor braking effect may also be managed by the IPEU (*e.g.*, via the controller 145/452).

[0076] The brake resistor 456 may be installed outside the IPEU, because a fair amount of heat may be generated during motor brake action. The brake energy may be limited (*e.g.*, associated with triplex pump). In such case, the resistor 456 may be mounted outside the IPEU and a fan may be included to limit the temperature increase during braking. In some applications, major brake action may occur, such as when the IPEU is controlling a rig drawworks. For example, the drawworks motor may deliver its full power during 30 seconds, representing an energy in the range of 60 Mjoules (2 Mwatt for 30 sec), which would increase the temperature of one ton of water by 15 degrees Celsius.

[0077] Thus, as shown in FIG. 16, an IPEU 500 may include a water-submerged implementation of the brake resistor 456. The IPEU 500 depicted FIG. 16 is the same as the IPEU 100 depicted in FIG. 3 except as described below. Elements depicted in FIG. 3 but not in FIG. 16 may nonetheless exist in the IPEU 500. Water 458 may be circulated by a pump 460 driven by motor 462 associated with a VFD 464 of the IPEU 500. The water 458 may be circulated with a reservoir 466 of one ton (1 M3) of water, and/or another volume permitting a predetermined number (*e.g.*, three) of long brake actions at full load. Quick disconnects and/or

other connection means 470 may be utilized to connect tubing and/or other conduits between the reservoir 466 and the pump 460, and between the reservoir 466 and a container 472 of the water-submerged brake resistor 456.

[0078] IPEU implementations within the scope of the present disclosure may be water tight. For example, the IPEU may have an International/Ingress Protection Rating of IP54, such that ingress of dust is not entirely prevented but does not enter in sufficient quantity to interfere with satisfactory operation, there is complete protection against contact, and water splashing against the housing 105 from any direction has no harmful effect. However, other IP ratings are also within the scope of the present disclosure.

[0079] IPEU implementations within the scope of the present disclosure may be designed to operate in NEC Zone 2. The safety requirements of zone 2 may be provided by implementations as depicted in FIGS. 17-19, in which an IPEU is utilized to drive various rig equipment. The IPEU of each implementation depicted in FIGS. 17-19 is the same as the IPEU 100 shown in FIG. 3, the IPEU 500 shown in FIG. 16, and/or other IPEU implementations within the scope of the present disclosure.

[0080] FIG. 17 is a schematic view of an implementation in which an IPEU 502 is utilized to drive a motor 504 of a skid-mounted rig machine 506, such as a triplex or other mud pump, a drawworks, and/or other high-power machines. The rig machine 506 is mounted on a skid 508, and the motor 504 is mounted on the rig machine 506 (or the skid 508). The IPEU 502 is mounted on the motor 504 via a deformable attachment 510. The deformable attachment 510 may comprise rubber, springs, shocks, and/or other means for dampening vibration of the motor 504 and/or the rig machine 506. A cable 503 provides power from the IPEU 502 to the motor 504.

[0081] FIG. 18 is a schematic view of a similar implementation in which the IPEU 502 is mounted on a support 509 that is mounted on the skid 508. The support 509 may be various structure sturdy enough to support the IPEU 502. The deformable attachment 510 may still be utilized between the IPEU 502 and the support 509.

[0082] In FIG. 19, an IPEU 512 is utilized to drive a motor 514 of a top drive 516. In such implementations, the power cable 513 may be part of the service loop connected to the top drive 516, and the IPEU 512 may be mounted on the rig floor 518, on the motor 514 and/or top drive 516, and/or to the mast 520. In each such case, the deformable attachment 510 may still be utilized.

[0083] As in the example implementations depicted in FIGS. 17-19, the IPEU may be mounted next to the motor that it operates. In many applications (mud pumps, drawworks, *etc.*), the IPEU may be mounted on the machine skid or even directly on the motor. In such cases, the power cable between the IPEU and the motor may be very short. Such cable may be internal to the mounting system or inside a conduit between the IPEU and the motor. With such cabling, electrical resonance may be minimized.

[0084] The deformable attachment 510 may reduce the vibration in the IPEU, and may reduce the risk of excitation of resonance, which may damage some electronic components. In some applications, the main resonance frequency may be affected by adjusting a spring coefficient of the deformable attachment 510. In other applications, the dampening may be affected to reduce the Q-factor of some mechanical resonance.

[0085] Power is fed power to the IPEU by cable(s). When multiple IPEUs are mounted on one large skid, the IPEUs may be connected in daisy chain or other connection schemes. The control of the IPEUs may be obtained via a control cable (*e.g.*, a hybrid cable for command and emergency stop) or wireless. If wireless, special wireless communication may be provided to perform the function of emergency stop.

[0086] FIG. 20 is a schematic view of at least a portion of an example implementation of a skid 600 according to one or more aspects of the present disclosure. Although the example skid 600 depicted in FIG. 20 is a mud pump skid, a person having ordinary skill in the art will readily recognize that the aspects described herein are also applicable or readily adaptable to a drawworks skid and other wellsite equipment.

[0087] The skid 600 includes a mud pump 605 attached to the skid. The mud pump 605 may be or comprise triplex pumps and/or other types of pumps. A centrifugal pump 610 driven by a motor 615 operates in conjunction with the mud pump 605. A main motor 620 drives the mud pump 605 via a belt system, a chain system, and/or other drive train 625. The motor 620 may be a large induction motor, such as having a power rating between about 400 HP and about 2500 HP, and/or otherwise operable to sufficiently drive the mud pump 605. In other implementations, the motor 620, perhaps still within the 400-2500 HP range, is operable to sufficiently drive a drawworks, a top drive, or other high-power rig equipment. As described above, a VFD of an IPEU 601 drives the motor 620, and the primary radiator 625 and the fans 650 manage heat generated during operation of the IPEU 601. The IPEU 601 is the same as the

IPEU 100 shown in FIG. 3, the IPEU 500 shown in FIG. 16, and/or other IPEU implementations within the scope of the present disclosure.

[0088] The skid 600 also includes an isolator 630 to decrease vibration of the skid 600 (*e.g.*, resulting from vibration of the mud pump 605) transmitted to the IPEU 601. For example, the isolator 630 may be the deformable attachment 510 described above, and may comprise rubber or other compliant materials, springs, shocks, and/or other vibration damping means.

[0089] The mud pump 605 includes a lubrication system comprising an oil pump 635 driven by a motor 640. The lubrication system may include a cooling system comprising a fan 645 driven by a motor 646. The mud pump 605 may also include a piston cleaning system comprising a water pump 655 driven by a motor 660. Electrical power and control of the centrifugal pump motor 615, the oil pump motor 640, the cooling fan motor 646, and/or the water pump motor 660 may be via the IPEU 601. Such control may be via wired and/or wireless communication.

[0090] The IPEU 601 may control each of the motors 651, 615, 620, 640, 646, and 660 (among other possible motors included in the skid) for start/stop operation, as well as speed control where applicable. Various sensors (not shown) may be associated with one or more of the motors. For example, a pressure gauge associated with the lubrication system of the mud pump 605 may be utilized to verify the lubrication pump is delivering the correct pressure. If the lubrication pressure is not adequate, the integrated control system implemented by the IPEU 601 may prohibit operation of the main motor 620. Similar motor activation and control of the result of the motor activation may be implemented for the cooling system, whether for air-cooled systems, liquid-cooled systems, or combinations thereof, including the cooling systems described above. For example, information obtained via a temperature sensor installed in one or more locations may be utilized by the IPEU 601 to control the result of the intended cooling effect. Various additional examples exist for how the IPEU 601 may control certain components of the skid based on information sensed from other components of the skid, as well as information obtained elsewhere.

[0091] As described above, the “integrated system” introduced in the present disclosure includes an internal control system to manage each of the auxiliary functions utilized for the efficient and safe operation of a mud pump or drawworks winch. The same applies to other implementations in which the main motor and the IPEU are at least partially integrated with a top drive and/or other main rig components. With such implementation, the rig control system may

not be burdened with performing “local” decisions specific to a given mud pump skid, drawworks skid, top drive system, and/or other main rig machine. Instead, the rig control system may manage just the factors linked to the drilling rig and the drilling process as a whole.

Consequently, even if a different machine is installed on the rig, the rig control system can just determine the drilling parameters and not deal with the local parameters of a specific machine.

[0092] The control system of the integrated skid may contain the parameters and logic to coordinate the axillary functions of the integrated skid in accordance with intended operation related to the drilling rig, as specified by the central computer of the drilling rig. For example, the control system of the integrated skid may hold calibration parameters of some or each of the sensors associated with the main and auxiliary machines of the skid. The control system may also hold other operational, maintenance (*e.g.*, replacement parts and schedules), usage, and other information related to the main and auxiliary machines of the skid.

[0093] The integrated skid may have simple connection to the rig system, such as a single power cable (*e.g.*, 600 V AC, 4160 V AC, or even DC) to feed power to the skid, and perhaps a control cable and/or wireless communication means to permit control of the skid equipment by the central computer of the rig. For example, the mud pumps, drawworks, top drive, and other primary machines contemplated by the present disclosure are large and high-powered, and consequently have an “emergency stop” function. The “emergency stop” button may be located in the driller’s control room (DCR) or a primary power/control room (PCR) of the rig. Thus, dedicated wired or wireless communication can be used between the “emergency stop” button and the control function of the integrated skid to ensure the “stop” of the skid equipment when urgency mandates.

[0094] FIG. 21 is a schematic view of at least a portion of an example implementation of a processing system 800 according to one or more aspects of the present disclosure. The processing system 800 may execute example machine-readable instructions to implement at least a portion of one or more of the methods and/or processes described herein, and/or to implement a portion of one or more of the example downhole tools described herein. The processing system 800 may be or comprise, for example, one or more processors, controllers, special-purpose computing devices, servers, personal computers, personal digital assistant (PDA) devices, smartphones, internet appliances, and/or other types of computing devices. The controller 145 described above and/or other controllers within the scope of the present disclosure may be implemented by one or more instances of at least a portion of the processing system 800.

[0095] The processing system 800 may comprise a processor 812, such as a general-purpose programmable processor, for example. The processor 812 may comprise a local memory 814, and may execute program code instructions 832 present in the local memory 814 and/or another memory device. The processor 812 may execute, among other things, machine-readable instructions or programs to implement the methods and/or processes described herein. The programs stored in the local memory 814 may include program instructions or computer program code that, when executed by an associated processor, cause a controller and/or control system implemented in surface equipment and/or a downhole tool to perform tasks as described herein. The processor 812 may be, comprise, or be implemented by one or more processors of various types operable in the local application environment, and may include one or more general-purpose processors, special-purpose processors, microprocessors, digital signal processors (DSPs), field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), processors based on a multi-core processor architecture, and/or other processors.

[0096] The processor 812 may be in communication with a main memory 817, such as via a bus 822 and/or other communication means. The main memory 817 may comprise a volatile memory 818 and a non-volatile memory 820. The volatile memory 818 may be, comprise, or be implemented by random access memory (RAM), static random access memory (SRAM), synchronous dynamic random access memory (SDRAM), dynamic random access memory (DRAM), RAMBUS dynamic random access memory (RDRAM), and/or other types of random access memory devices. The non-volatile memory 820 may be, comprise, or be implemented by read-only memory, flash memory, and/or other types of memory devices. One or more memory controllers (not shown) may control access to the volatile memory 818 and/or the non-volatile memory 820.

[0097] The processing system 800 may also comprise an interface circuit 824. The interface circuit 824 may be, comprise, or be implemented by various types of standard interfaces, such as an Ethernet interface, a universal serial bus (USB), a third generation input/output (3GIO) interface, a wireless interface, and/or a cellular interface, among other examples. The interface circuit 824 may also comprise a graphics driver card. The interface circuit 824 may also comprise a communication device, such as a modem or network interface card, to facilitate exchange of data with external computing devices via a network, such as via Ethernet connection, digital subscriber line (DSL), telephone line, coaxial cable, cellular telephone system, and/or satellite, among other examples.

[0098] One or more input devices 826 may be connected to the interface circuit 824. One or more of the input devices 826 may permit a user to enter data and/or commands for utilization by the processor 812. Each input device 826 may be, comprise, or be implemented by a keyboard, a mouse, a touchscreen, a track-pad, a trackball, an image/code scanner, and/or a voice recognition system, among other examples.

[0099] One or more output devices 828 may also be connected to the interface circuit 824. One or more of the output devices 828 may be, comprise, or be implemented by a display device, such as a liquid crystal display (LCD), a light-emitting diode (LED) display, and/or a cathode ray tube (CRT) display, among other examples. One or more of the output devices 828 may also or instead be, comprise, or be implemented by a printer, speaker, and/or other examples.

[00100] The processing system 800 may also comprise a mass storage device 830 for storing machine-readable instructions and data. The mass storage device 830 may be connected to the interface circuit 824, such as via the bus 822. The mass storage device 830 may be or comprise a floppy disk drive, a hard disk drive, a compact disk (CD) drive, and/or digital versatile disk (DVD) drive, among other examples. The program code instructions 832 may be stored in the mass storage device 830, the volatile memory 818, the non-volatile memory 820, the local memory 814, and/or on a removable storage medium 834, such as a CD or DVD.

[00101] The mass storage device 830, the volatile memory 818, the non-volatile memory 820, the local memory 814, and/or the removable storage medium 834 may each be a tangible, non-transitory storage medium. The modules and/or other components of the processing system 800 may be implemented in accordance with hardware (such as in one or more integrated circuit chips, such as an ASIC), or may be implemented as software or firmware for execution by a processor. In the case of firmware or software, the implementation can be provided as a computer program product including a computer readable medium or storage structure containing computer program code (*i.e.*, software or firmware) for execution by the processor.

[00102] In view of the entirety of the present disclosure, including the figures and the claims, a person having ordinary skill in the art will readily recognize that the present disclosure introduces an apparatus comprising an IPEU operable for providing output power for driving an electric motor of a drilling rig machine, wherein the IPEU comprises: (A) a housing; (B) a radiator mounted within the housing and comprising radiating members each extending through an opening in the housing; and (C) a VFD comprising: (i) a plurality of IGBTs operable to convert input power to the output power, wherein the IGBTs are coupled to the radiator within

the housing such that heat generated by the IGBTs is transferred out of the housing via the radiator; and (ii) a controller operable to control the IGBTs.

[00103] The IPEU may comprise: an input power bulkhead connector for receiving electrical power from a power source; one or more communication bulkhead connectors for receiving data and/or control signals from one or more data and/or control sources; and/or an output power bulkhead connector for providing the output power to the motor driven by the IPEU.

[00104] The VFD may be a first VFD and the IPEU may comprise: a fan driven by a fan motor and operable to increase airflow across the radiating members; and a second VFD operable to energize the fan motor. The IPEU may comprise ducting attached to the housing, such as to focus airflow across the radiating members. The radiator may be a primary radiator, the radiating members may be first radiating members, the opening may be a first opening, the IPEU may comprise a secondary radiator mounted within the housing, and the secondary radiator may comprise second radiating members each extending externally through a second opening in the housing. The fan may be a first fan, the fan motor may be a first fan motor, the IPEU may comprise a second fan driven by a second fan motor and operable to increase airflow across the second radiating member, and the second VFD may be operable to energize the second fan motor. The ducting may be first ducting, and the IPEU may comprise second ducting attached to the housing, such as to focus airflow across the second radiating members. The secondary radiator may comprise: a base plate secured within the housing, wherein the second radiating members may be integral or coupled to the base plate; and elongated members extending internally from the base plate within the housing, wherein the elongated members may be integral or coupled to the base plate. The IPEU may comprise: an internal fan operable to increase airflow across the elongated members of the secondary radiator; and an internal motor energized by the second VFD.

[00105] The IPEU may comprise a radiation shield providing protection against heat transfer by radiation into and out of the housing.

[00106] The radiator may comprise a filter blocking particles large enough to clog the radiating members.

[00107] Each radiating member may be a cylinder equipped with radial extensions interlaced with radial extensions of neighboring radiating members.

[00108] The radiator may comprise a base plate secured within the housing, and the radiating members may be integral or coupled to the base plate. Lengths of the radiating members may be

progressively larger along a direction of air flow through the radiating members. Thickness of the base plate may be progressively larger along a direction of air flow through the radiating members. Packing density of the radiating members may be progressively greater along a direction of air flow through the radiating members.

[00109] The IPEU may comprise a nozzle operable to spray water toward and/or on the radiating members.

[00110] The IPEU may comprise a nozzle operable to direct compressed air toward the radiating members.

[00111] The VFD may be a first VFD, the housing may comprise a chimney extending through the housing, the opening in the housing through which the radiating members extend may be an opening in the chimney, and the IPEU may comprise: a fan operable to direct air external to the housing through the chimney; a motor operable to drive the fan; and a second VFD operable to energize the fan motor. The IPEU may comprise an exhaust tube pivotably attached to the housing at an exit of the chimney such that external wind spins the exhaust tube toward a downwind direction. The chimney may have a paraboloid-hyperbolic shape. The IPEU may comprise a container comprising silica gel able to absorb moisture within the housing. The IPEU may comprise a container comprising: a first door openable into an interior of the housing via operation of a first actuator; a second door openable into an interior of the chimney via operation of a second actuator; and first and second barriers permitting passage of air while retaining silica gel within the container when either of the first and second doors open, wherein the silica gel is able to absorb moisture within the housing, and the controller may be operable to maintain the first door open until determining that the silica gel has become saturated, and then close the first door and open the second door to expose the saturated silica gel to air flow through the chimney to dry the saturated silica gel.

[00112] The IPEU may comprise a brake resistor and a chopper operable to evacuate excess DC power into the brake resistor. The brake resistor may be submerged in circulating water.

[00113] The apparatus may comprise the machine. The apparatus may also comprise a deformable attachment to which the IPEU is mounted to isolate the IPEU from vibration generated by the machine.

[00114] The machine may be a mud pump, a drawworks, or a top drive.

[00115] The foregoing outlines features of several embodiments so that a person having ordinary skill in the art may better understand the aspects of the present disclosure. A person

having ordinary skill in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same functions and/or achieving the same benefits of the embodiments introduced herein. A person having ordinary skill in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the present disclosure. Moreover, implementations within the scope of the present disclosure include those having features shown in multiple figures, including implementations comprising one or more instances of a first feature shown in a first figure combined with one or more instances of a second feature shown in a second figure, even though the first feature is not shown or described in association with the second figure and/or the second feature is not shown or described in association with the first figure. Thus, the scope of the present disclosure includes implementations combining features collectively shown in two or more different figures or otherwise described herein, even though none of such figures independently show each feature in such combination.

[00116] The Abstract at the end of this disclosure is provided to comply with 37 C.F.R. §1.72(b) to permit the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

WHAT IS CLAIMED IS:

1. An apparatus comprising:
an integrated power and electronics unit (IPEU) operable for providing output power for driving
an electric motor of a drilling rig machine, wherein the IPEU comprises:
 - a housing;
 - a radiator mounted within the housing and comprising radiating members each extending
through an opening in the housing; and
 - a variable frequency drive (VFD) comprising:
 - a plurality of insulated-gate bipolar transistor devices (IGBTs) operable to convert
input power to the output power, wherein the IGBTs are coupled to the
radiator within the housing such that heat generated by the IGBTs is
transferred out of the housing via the radiator; and
 - a controller operable to control the IGBTs.
2. The apparatus of claim 1 wherein the VFD is a first VFD and the IPEU comprises:
a fan driven by a fan motor and operable to increase airflow across the radiating members; and
a second VFD operable to energize the fan motor.
3. The apparatus of claim 2 wherein:
the radiator is a primary radiator;
the radiating members are first radiating members;
the opening is a first opening;
the IPEU comprises a secondary radiator mounted within the housing; and
the secondary radiator comprises second radiating members each extending externally through a
second opening in the housing.

4. The apparatus of claim 3 wherein:

the fan is a first fan;

the fan motor is a first fan motor;

the IPEU comprises a second fan driven by a second fan motor and operable to increase airflow across the second radiating member; and

the second VFD is operable to energize the second fan motor.

5. The apparatus of claim 3 wherein the secondary radiator comprises:

a base plate secured within the housing, wherein the second radiating members are integral or coupled to the base plate; and

elongated members extending internally from the base plate within the housing, wherein the elongated members are integral or coupled to the base plate.

6. The apparatus of claim 5 wherein the IPEU comprises:

an internal fan operable to increase airflow across the elongated members of the secondary radiator; and

an internal motor energized by the second VFD.

7. The apparatus of claim 1 wherein the IPEU comprises a radiation shield providing protection against heat transfer by radiation into and out of the housing.

8. The apparatus of claim 1 wherein the radiator comprises a filter blocking particles large enough to clog the radiating members.

9. The apparatus of claim 1 wherein:

the radiator comprises a base plate secured within the housing;

the radiating members are integral or coupled to the base plate; and

lengths of the radiating members are progressively larger along a direction of air flow through the radiating members.

10. The apparatus of claim 1 wherein:

the radiator comprises a base plate secured within the housing;
the radiating members are integral or coupled to the base plate; and
thickness of the base plate is progressively larger along a direction of air flow through the radiating members.

11. The apparatus of claim 1 wherein:

the radiator comprises a base plate secured within the housing;
the radiating members are integral or coupled to the base plate; and
packing density of the radiating members is progressively greater along a direction of air flow through the radiating members.

12. The apparatus of claim 1 wherein the IPEU comprises a nozzle operable to spray water toward and/or on the radiating members.

13. The apparatus of claim 1 wherein the IPEU comprises a nozzle operable to direct compressed air toward the radiating members.

14. The apparatus of claim 1 wherein:

the VFD is a first VFD;
the housing comprises a chimney extending through the housing;
the opening in the housing through which the radiating members extend is an opening in the chimney; and

the IPEU comprises:

a fan operable to direct air external to the housing through the chimney;
a motor operable to drive the fan; and
a second VFD operable to energize the fan motor.

15. The apparatus of claim 14 wherein:

the IPEU comprises a container comprising:

a first door openable into an interior of the housing via operation of a first actuator;

a second door openable into an interior of the chimney via operation of a second actuator;

and

first and second barriers permitting passage of air while retaining silica gel within the

container when either of the first and second doors open, wherein the silica gel is able

to absorb moisture within the housing; and

the controller is operable to maintain the first door open until determining that the silica gel has

become saturated, and then close the first door and open the second door to expose the

saturated silica gel to air flow through the chimney to dry the saturated silica gel.

16. The apparatus of claim 1 wherein the IPEU comprises a brake resistor and a chopper

operable to evacuate excess DC power into the brake resistor.

17. The apparatus of claim 1 further comprising:

the machine; and

a deformable attachment to which the IPEU is mounted to isolate the IPEU from vibration

generated by the machine.

18. The apparatus of claim 17 wherein the machine is a mud pump.

19. The apparatus of claim 17 wherein the machine is a drawworks.

20. The apparatus of claim 17 wherein the machine is a top drive.

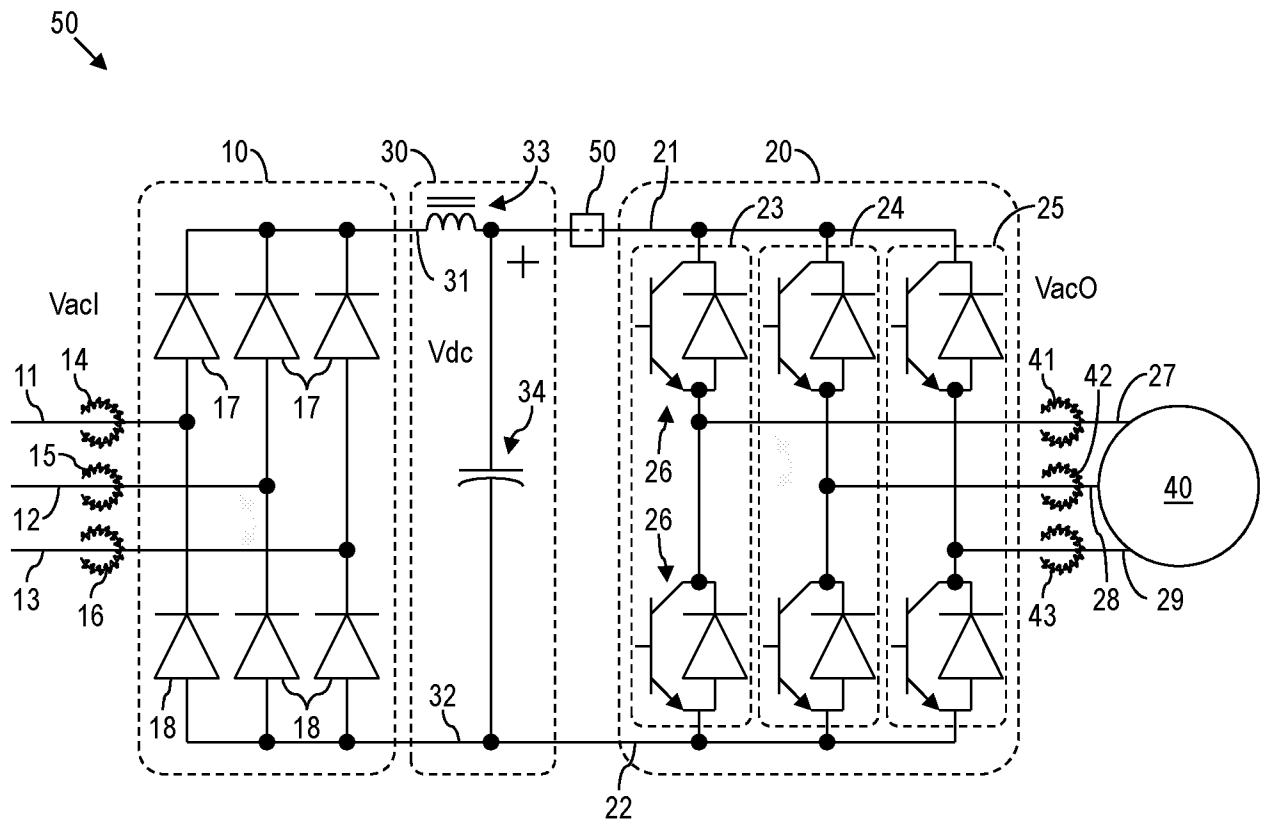


FIG. 1

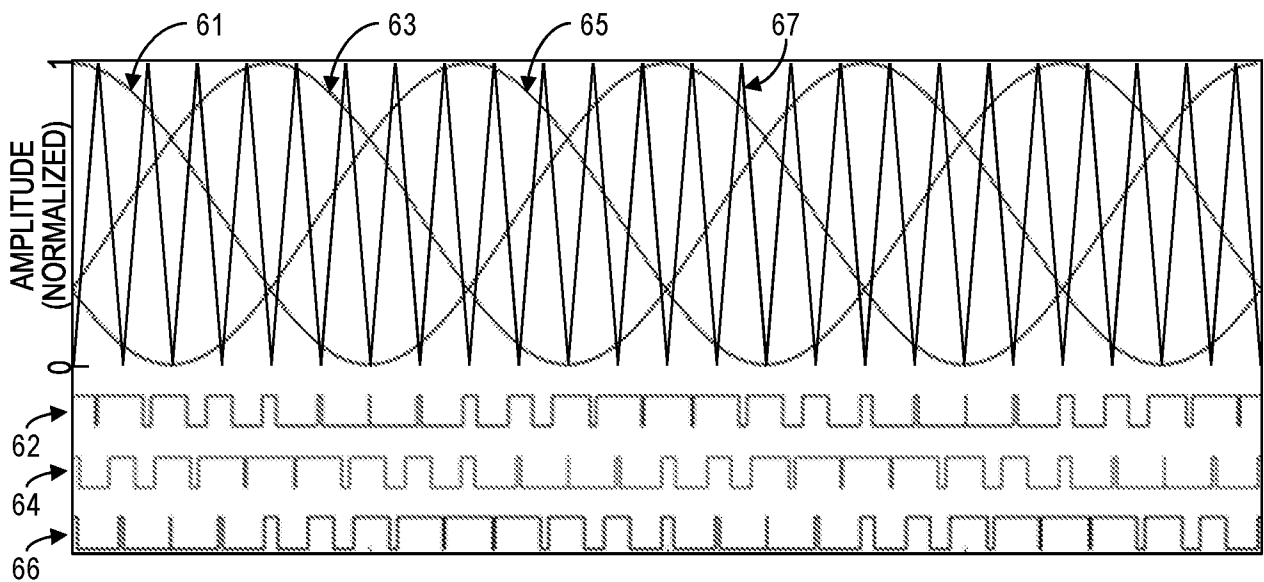


FIG. 2

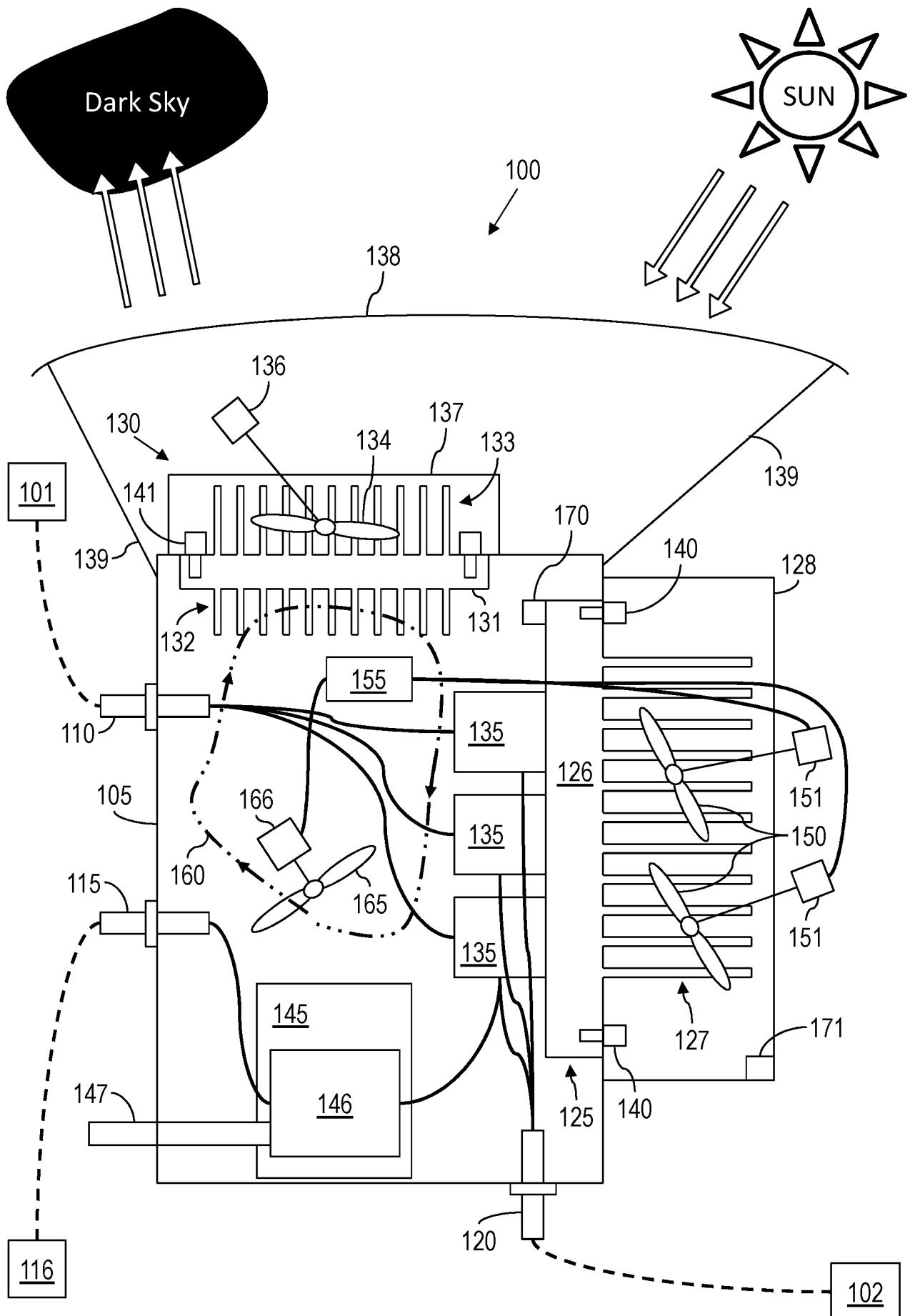


FIG. 3

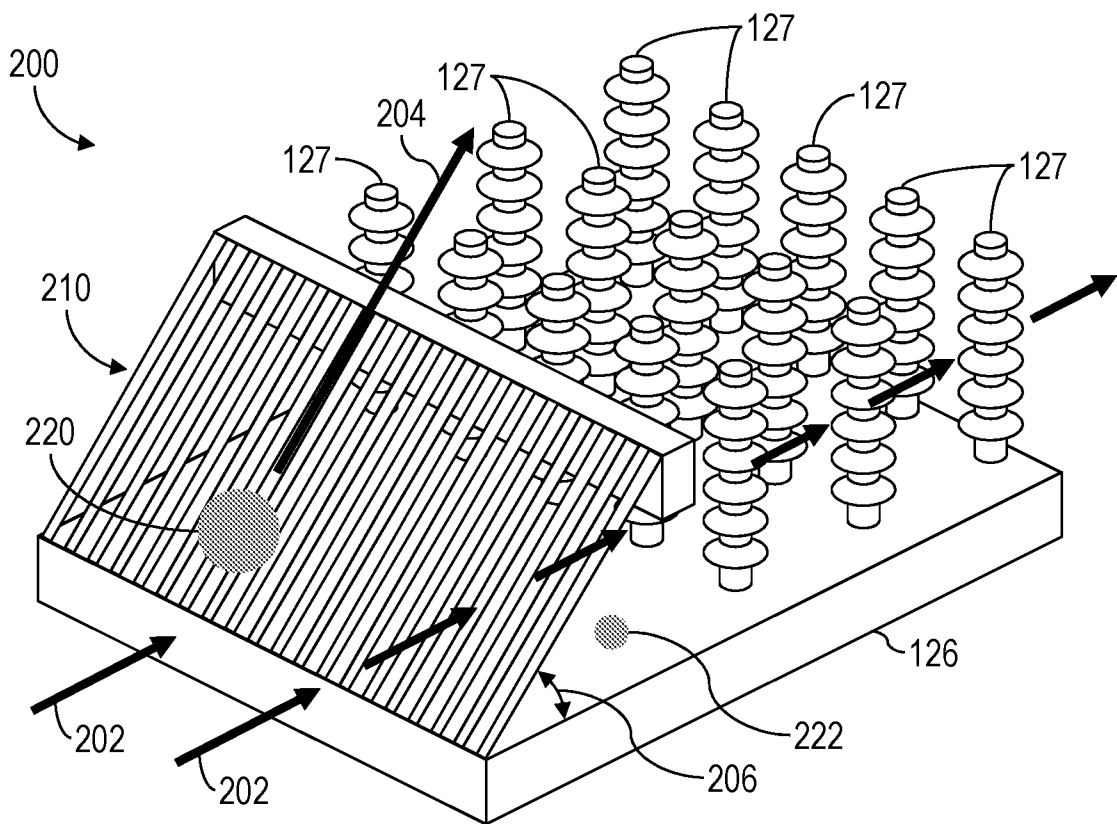


FIG. 4

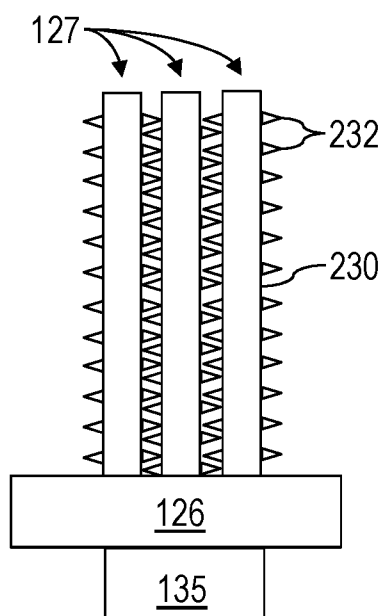


FIG. 5

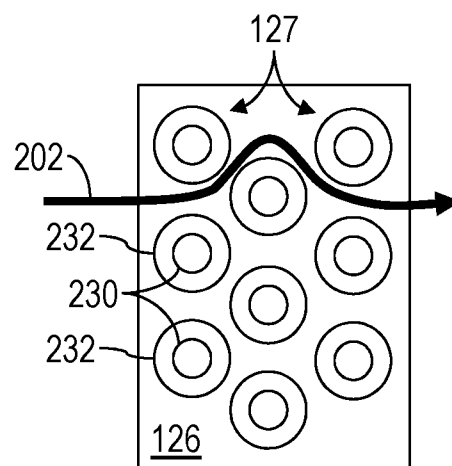
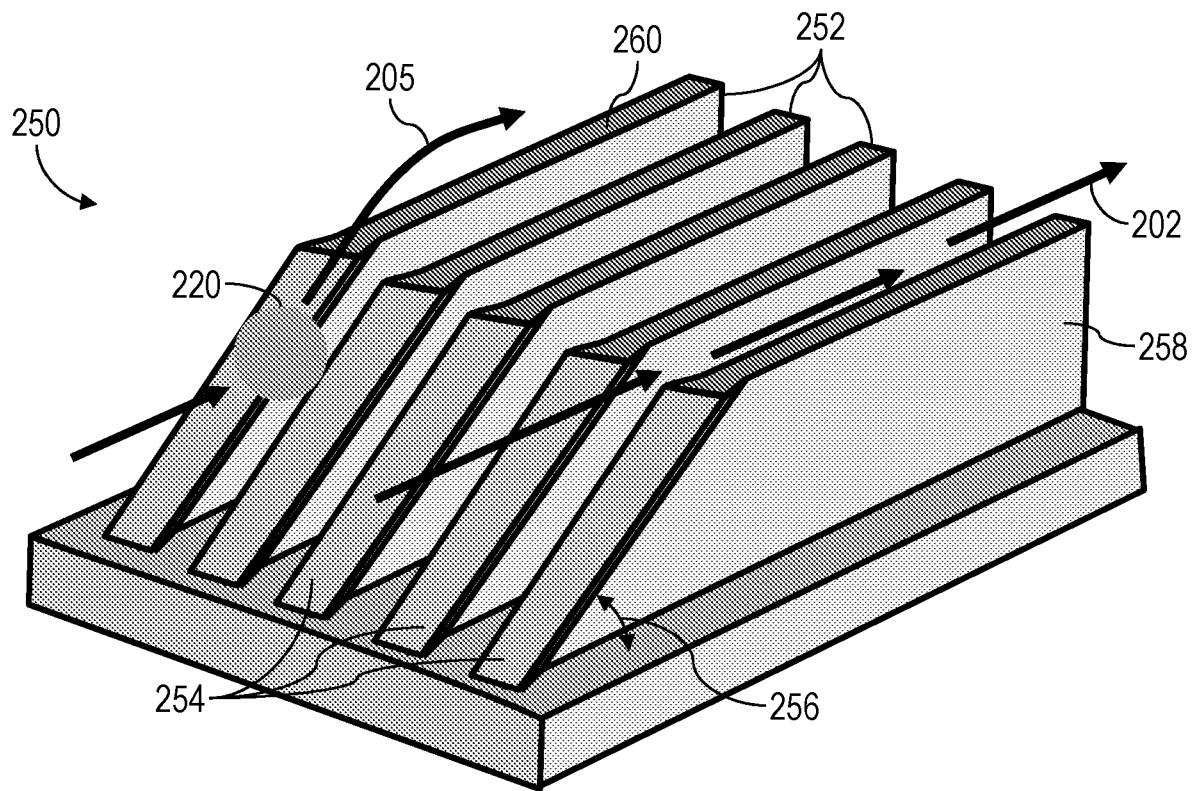
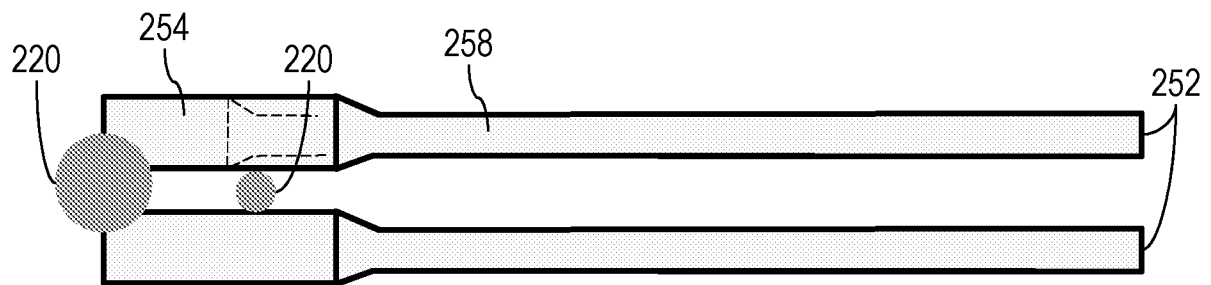


FIG. 6

*FIG. 7**FIG. 8*

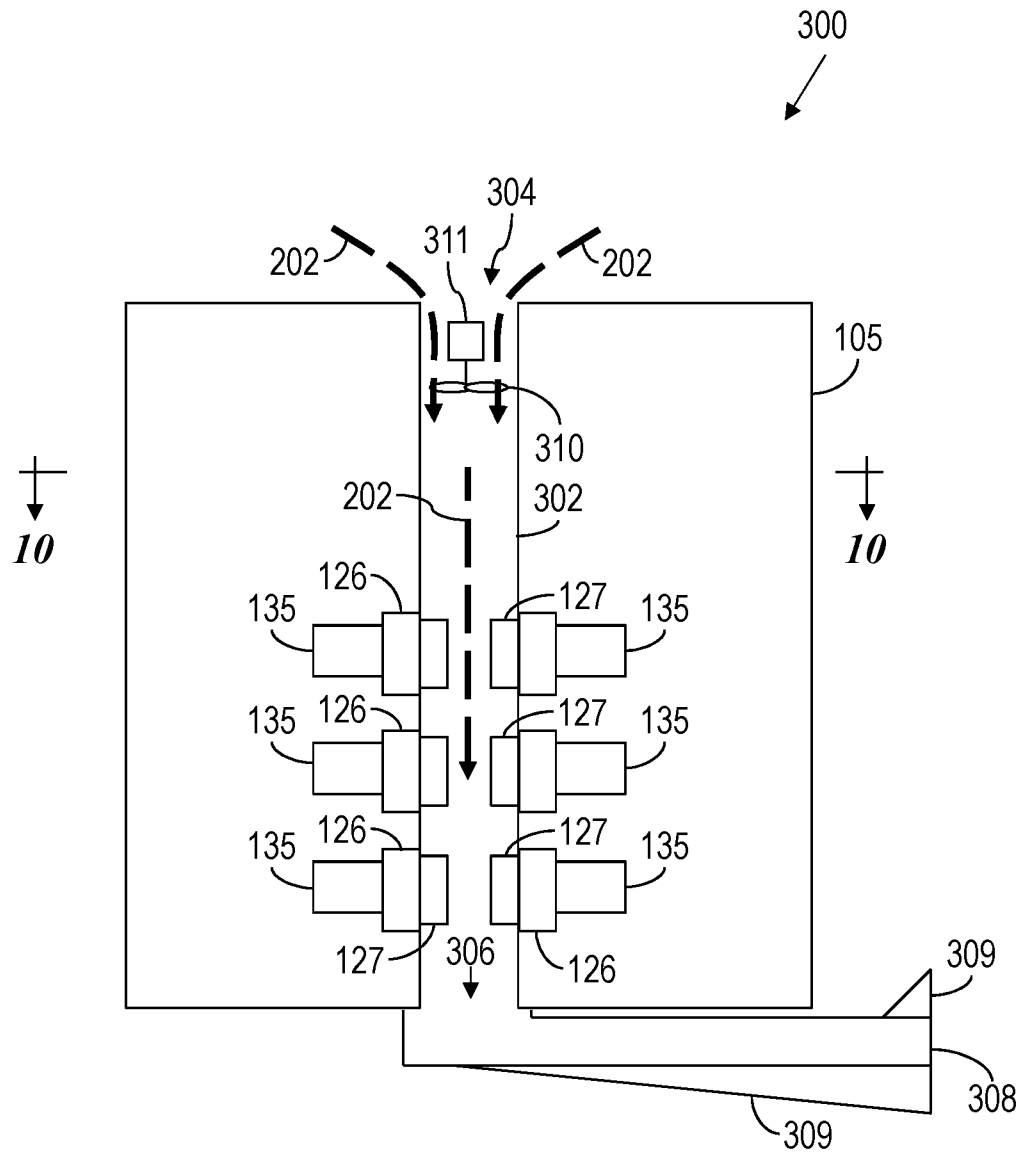


FIG. 9

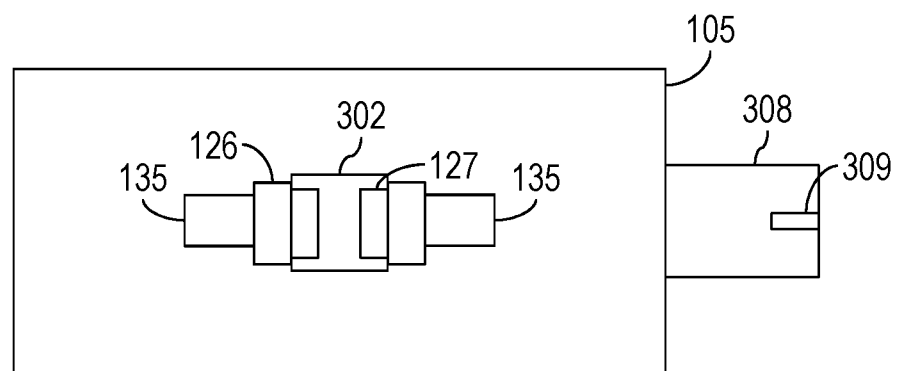


FIG. 10

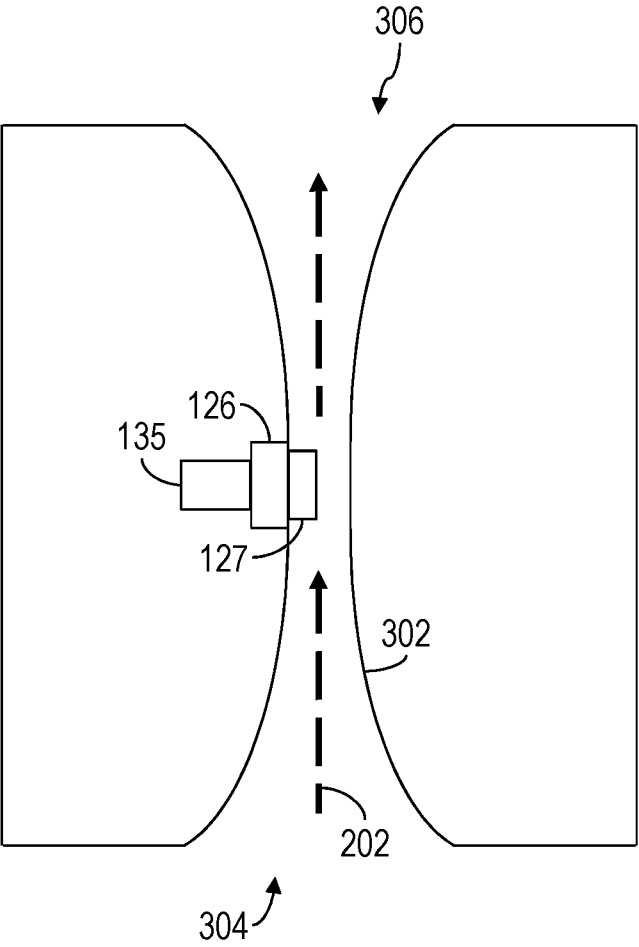


FIG. 11

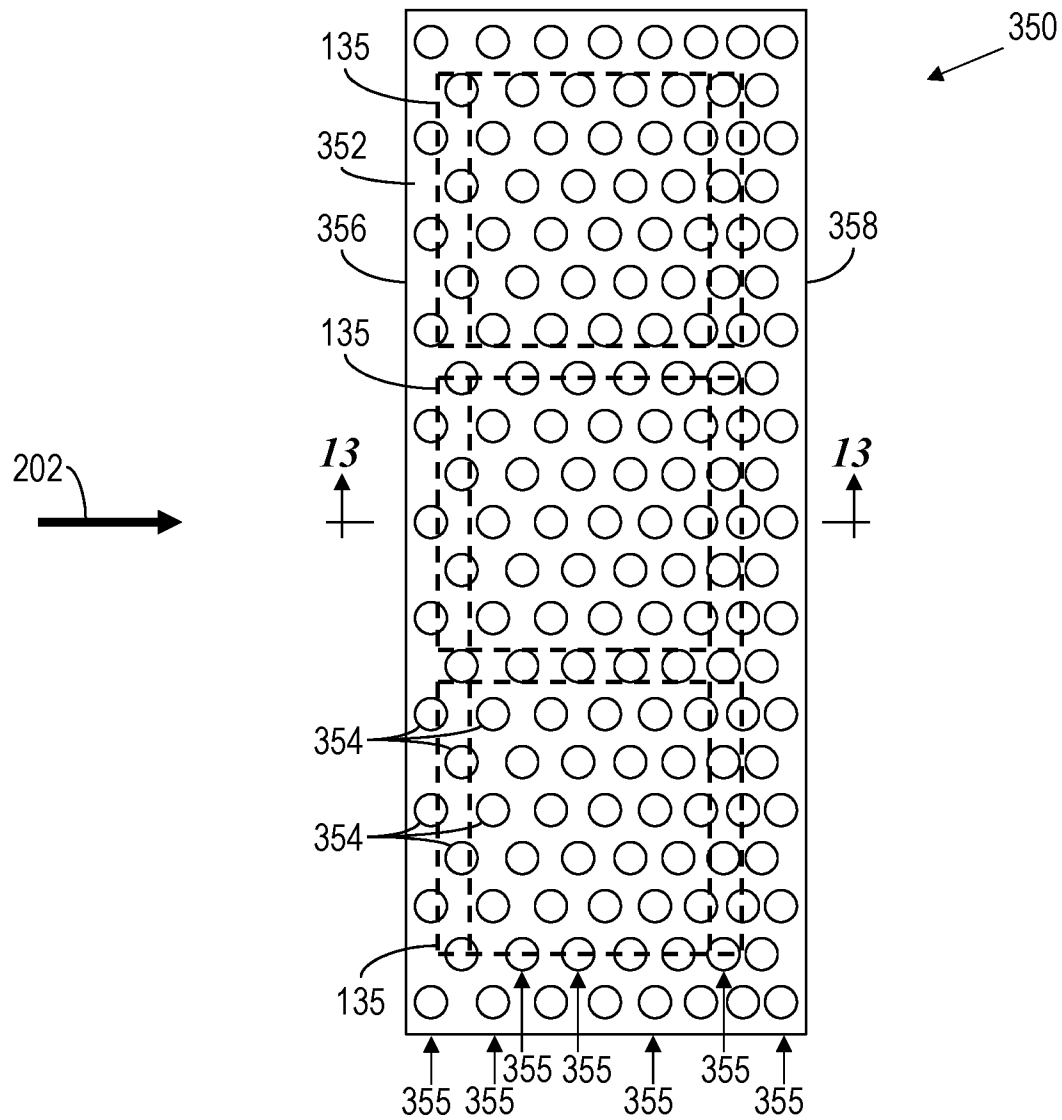


FIG. 12

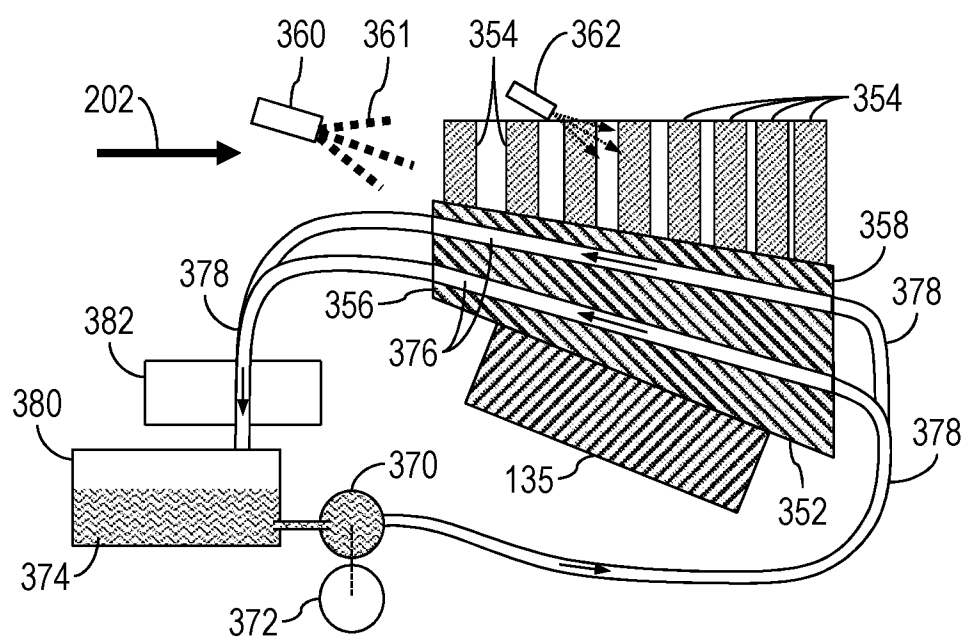


FIG. 13

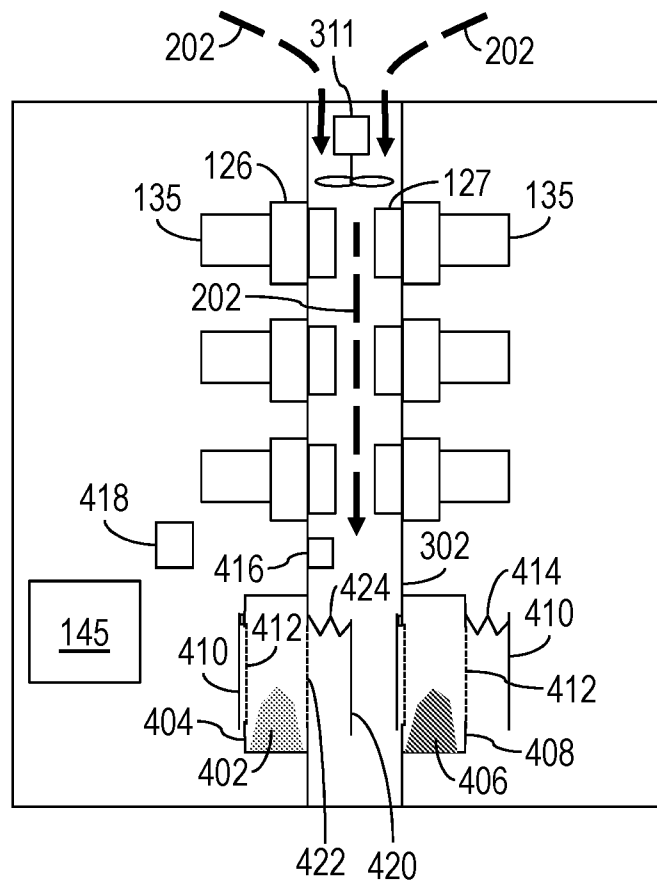
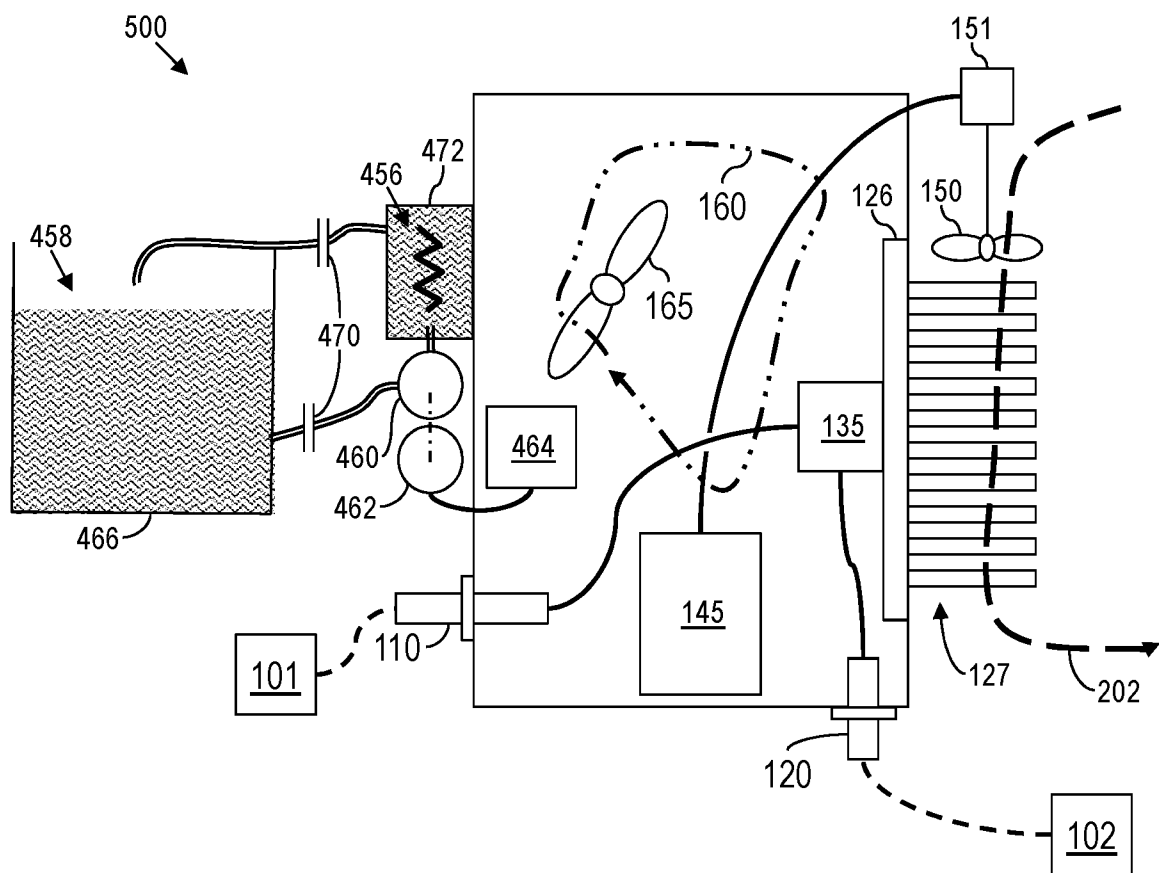
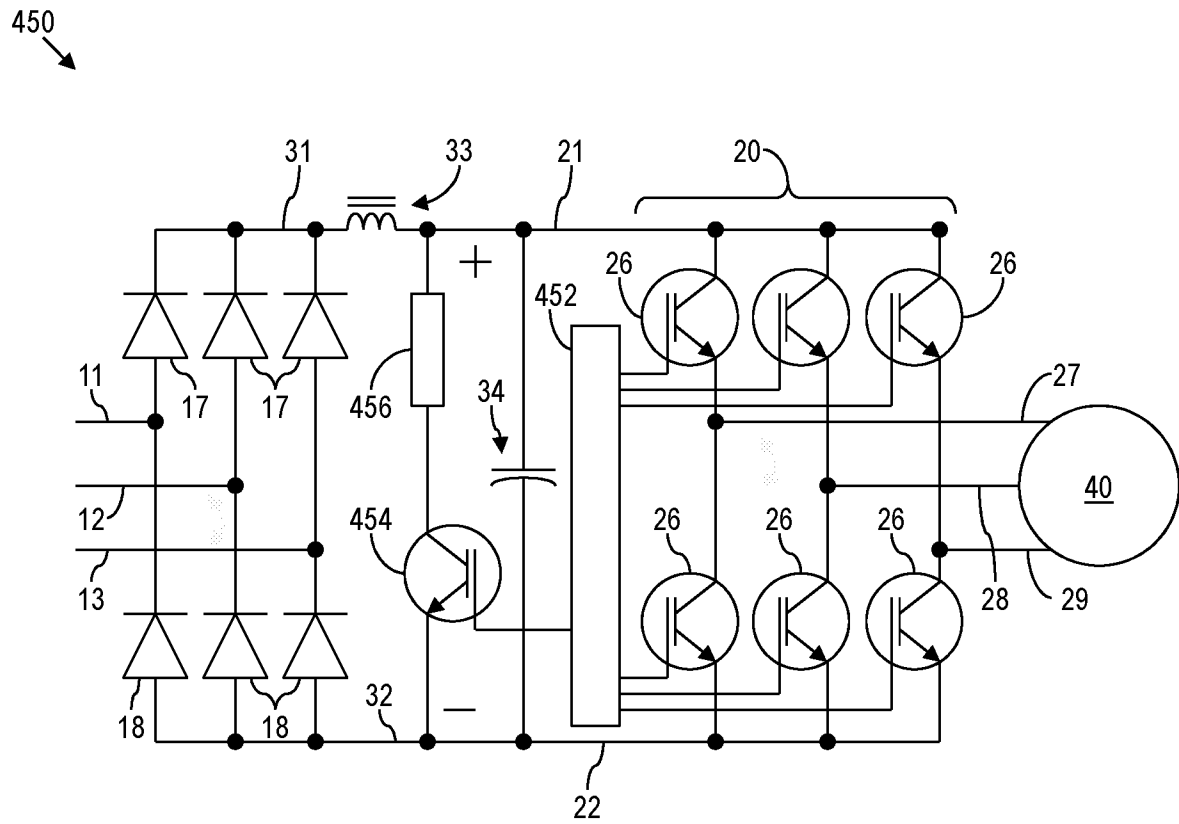


FIG. 14



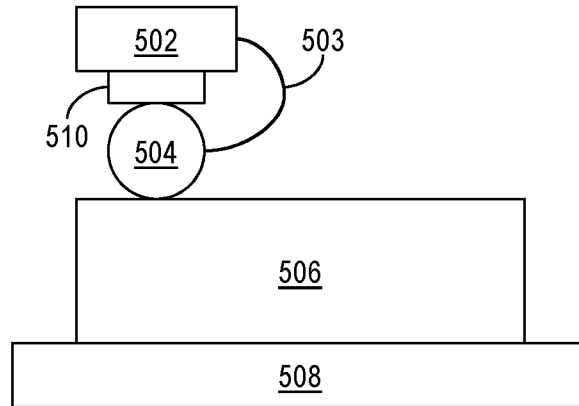


FIG. 17

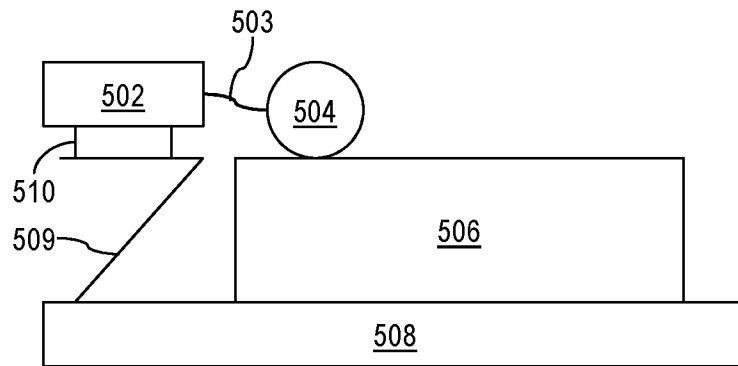


FIG. 18

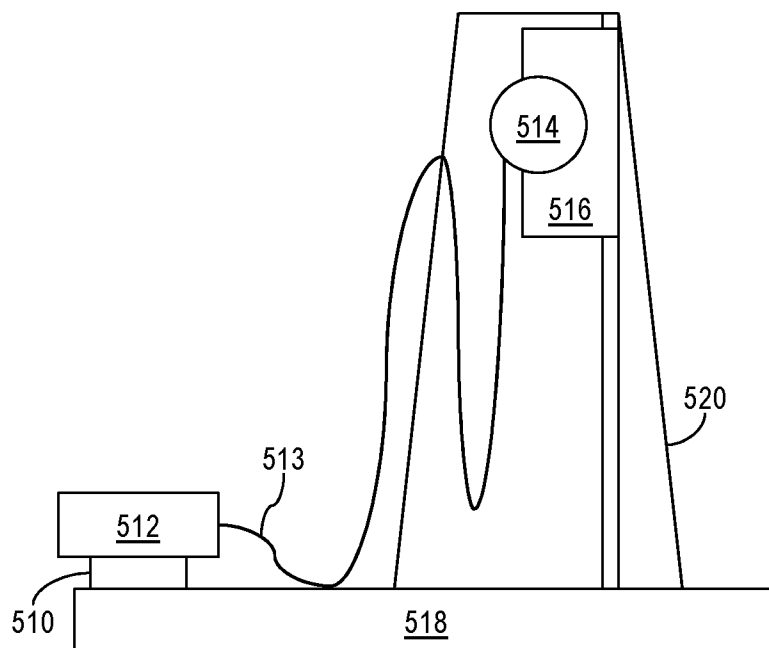


FIG. 19

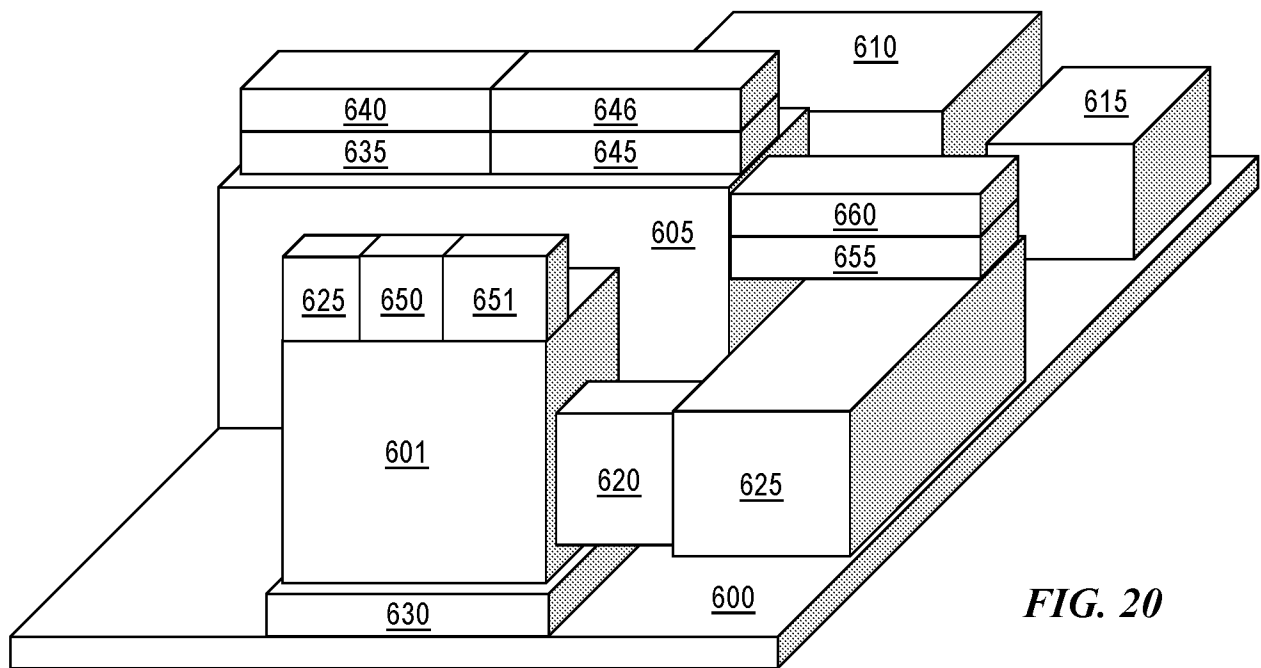


FIG. 20

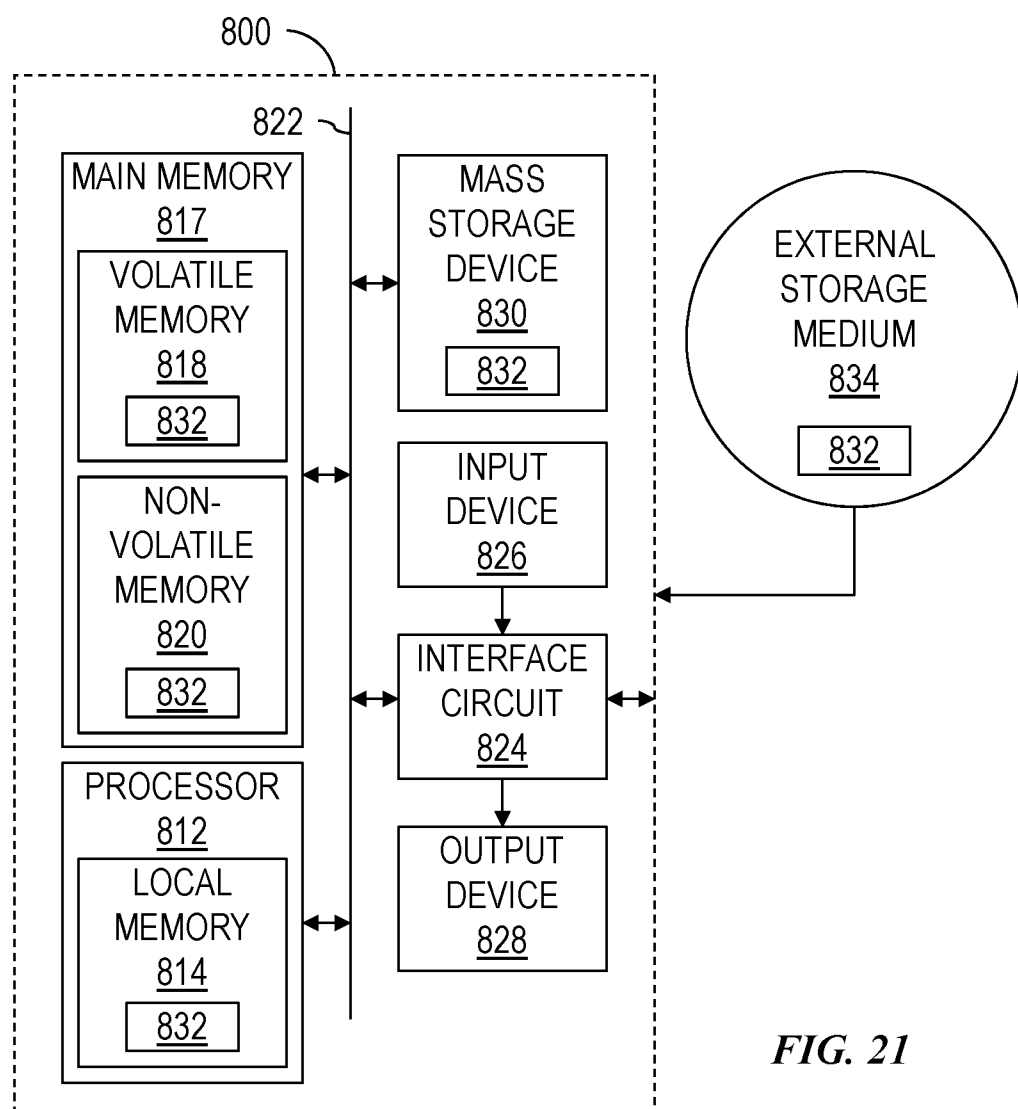


FIG. 21

A. CLASSIFICATION OF SUBJECT MATTER**E21B 41/00(2006.01)i, H02K 5/18(2006.01)i, H02P 27/04(2006.01)i**

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)

E21B 41/00; E21B 7/128; G06F 19/00; H05K 7/20; E21B 44/00; H02P 9/04; E21B 43/26; E21B 17/01; H02K 5/18; H02P 27/04

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: power unit, motor, housing, radiator, variable frequency drive, insulated-gate bipolar transistor, fan**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016-0258267 A1 (STEWART & STEVENSON, LLC.) 08 September 2016 See paragraphs [0046], [0047] and figure 3.	1-13, 16-20
A		14, 15
Y	EP 3016488 A1 (KONE CORPORATION) 04 May 2016 See paragraphs [0041]-[0049] and figures 1-2b.	1-13, 16-20
Y	US 2016-0088767 A1 (ABB TECHNOLOGY LTD.) 24 March 2016 See paragraphs [0058]-[0061] and figures 5, 6.	3-6
Y	US 2008-0203734 A1 (GRIMES et al.) 28 August 2008 See paragraph [0122] and figure 6.	16
Y	US 2016-0024853 A1 (DRIL-QUIP, INC.) 28 January 2016 See paragraphs [0020], [0021] and figures 1, 2.	17-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

14 August 2018 (14.08.2018)

Date of mailing of the international search report

14 August 2018 (14.08.2018)

Name and mailing address of the ISA/KR

International Application Division

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/030080

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