US012391394B2

(12) **United States Patent**
Abdelli et al.

(10) **Patent No.: US 12,391,394 B2**
(45) **Date of Patent: Aug. 19, 2025**

(54) **HIGH VOLTAGE CONVERTER FOR USE AS ELECTRIC POWER SUPPLY**

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(73) Assignee: **magniX USA Inc.**, Everett, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 133 days.

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(65) **Prior Publication Data**

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(Continued)

(51) **Int. Cl.**
H02K 16/00 (2006.01)
B64D 27/24 (2024.01)
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(52) **U.S. Cl.**
CPC ***H02K 16/00*** (2013.01); ***B64D 27/24*** (2013.01); ***B64D 31/02*** (2013.01); ***B64D 33/08*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H02K 16/00; H02K 11/21; H02K 11/30; H02K 5/203; H02K 5/225; H02K 7/116;
(Continued)

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Primary Examiner — Lincoln D Donovan
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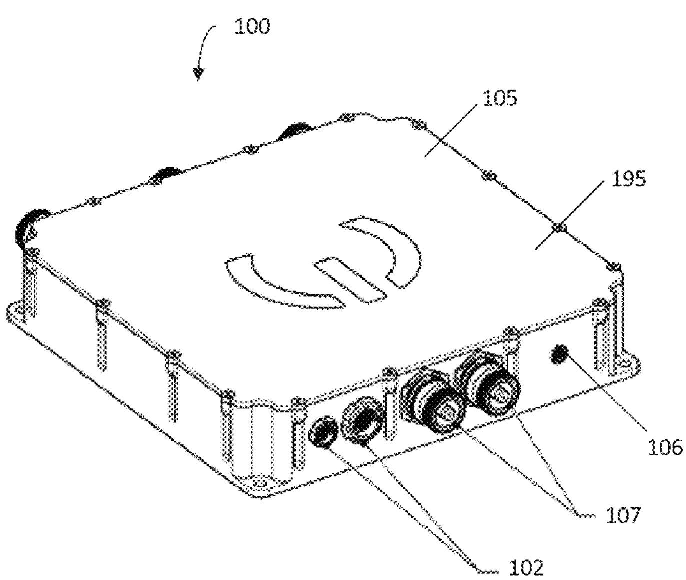
(74) *Attorney, Agent, or Firm* — Scully, Scott, Murphy & Presser, P.C.

(57) **ABSTRACT**

An electric power supply is described that has direct-current (DC) to alternating-current (AC) circuitry adapted and configured to receive DC power input having a DC input voltage and convert the DC power input to multi-phase, alternating-current (AC) power output. The DC to AC circuitry includes an electromagnetic interference (EMI) noise filter to suppress EMI noise, wherein the EMI noise filter comprises two, electrically insulated, conductive rails configured and adapted to receive the DC power input, ferrite material at least partially surrounding the two conductive rails, and a current sensing element positioned in a gap in the ferrite material and configured to measure leakage current escaping to ground.

30 Claims, 9 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/855,143, filed on May 31, 2019, provisional application No. 62/855,147, filed on May 31, 2019, provisional application No. 62/855,151, filed on May 31, 2019.

(51) **Int. Cl.**

B64D 31/02	(2006.01)
B64D 33/08	(2006.01)
B64D 41/00	(2006.01)
F16H 57/04	(2010.01)
H02J 7/34	(2006.01)
H02K 5/20	(2006.01)
H02K 5/22	(2006.01)
H02K 7/116	(2006.01)
H02K 9/197	(2006.01)
H02K 11/21	(2016.01)
H02K 11/30	(2016.01)
H02P 6/10	(2006.01)
H02P 25/16	(2006.01)
H02P 27/08	(2006.01)

(52) **U.S. Cl.**
CPC ***B64D 41/00*** (2013.01); ***F16H 57/0476*** (2013.01); ***H02J 7/345*** (2013.01); ***H02K 5/203*** (2021.01); ***H02K 5/225*** (2013.01); ***H02K 7/116*** (2013.01); ***H02K 9/197*** (2013.01); ***H02K 11/21*** (2016.01); ***H02K 11/30*** (2016.01); ***H02P 6/10*** (2013.01); ***H02P 25/16*** (2013.01); ***H02P 27/08*** (2013.01); *B64D 2221/00* (2013.01); *H02K 2213/06* (2013.01)

(58) **Field of Classification Search**
CPC H02K 9/197; H02K 2213/06; B64D 27/24; B64D 31/02; B64D 33/08; B64D 41/00; B64D 2221/00; F16H 57/0476; H02J 7/345; H02P 6/10; H02P 25/16; H02P 27/08
See application file for complete search history.

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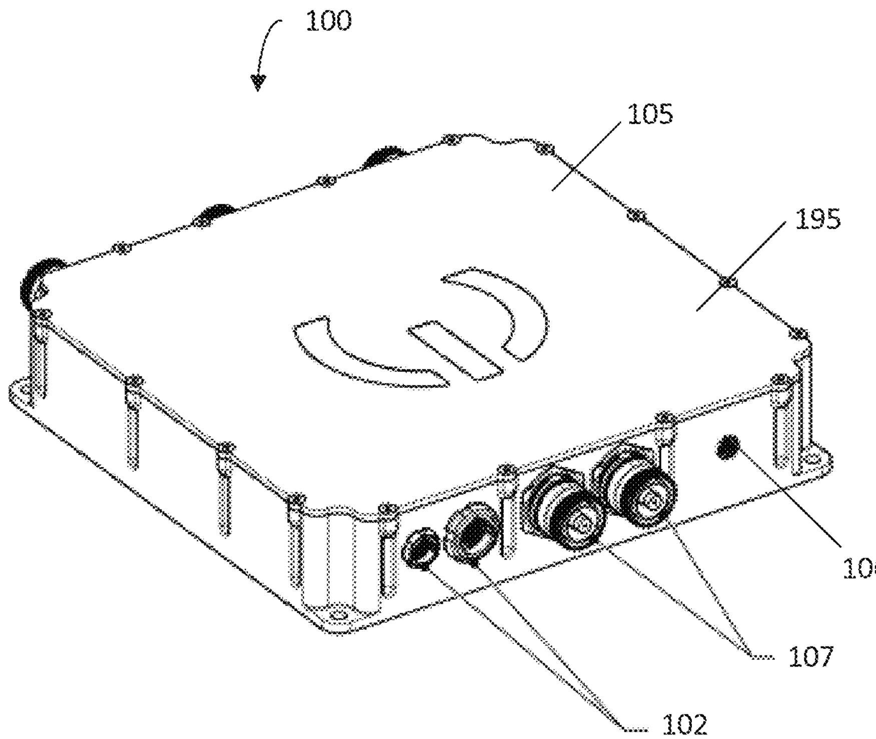


FIG. 1

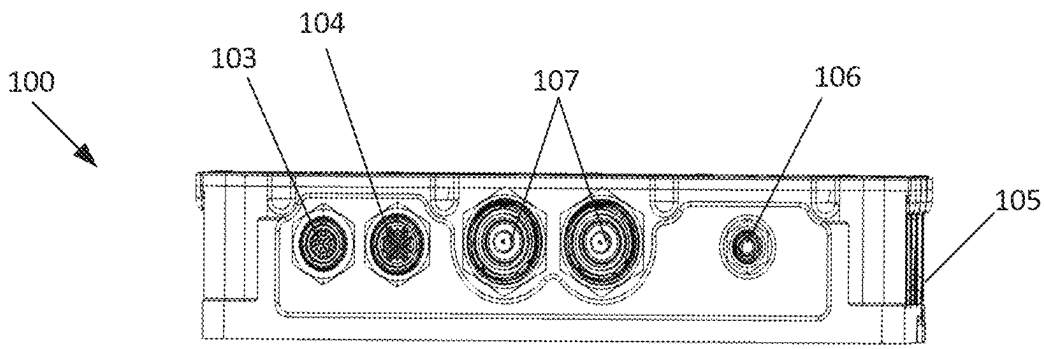


FIG. 2

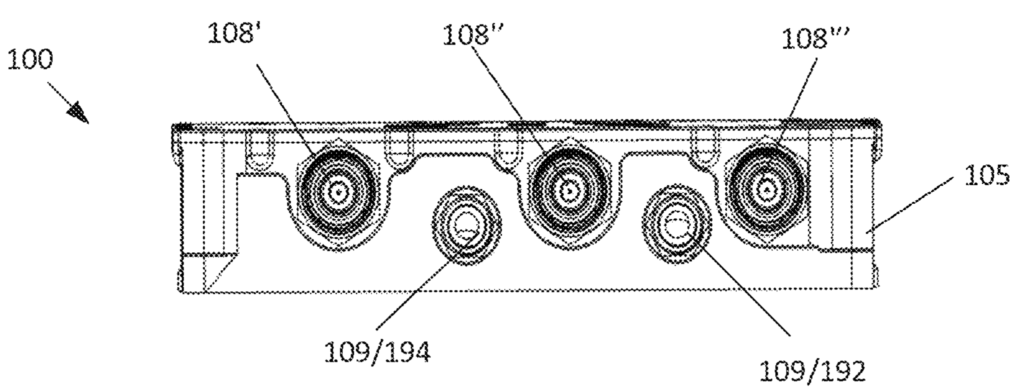


FIG. 4

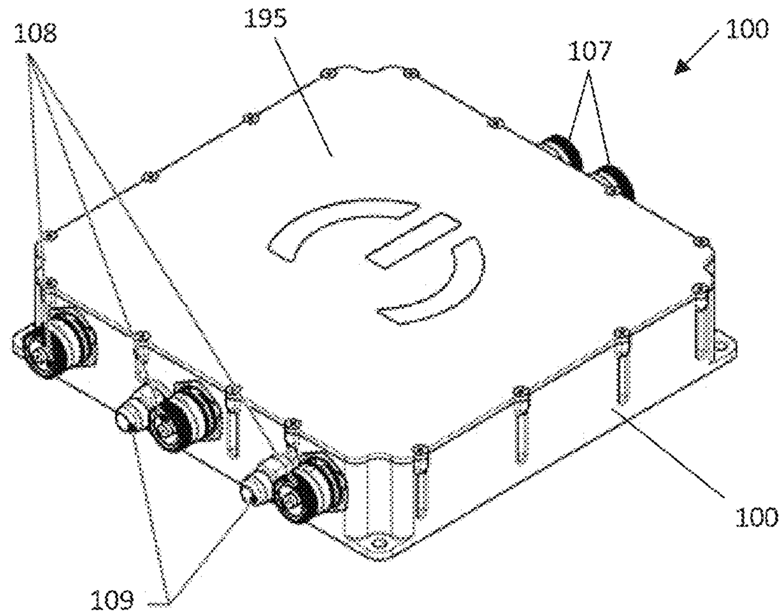
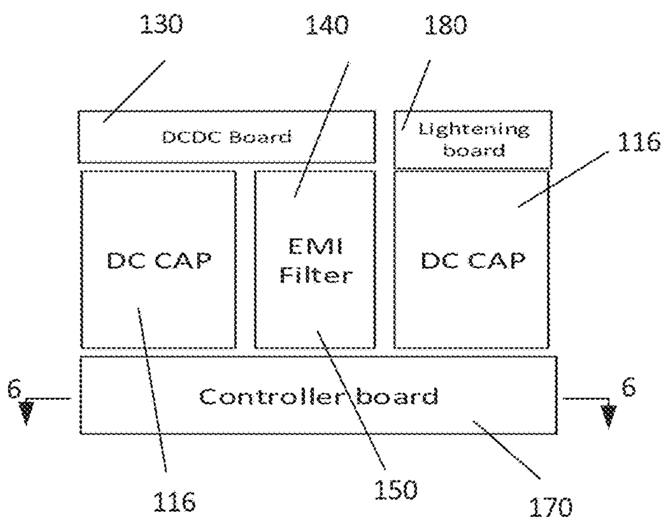


FIG. 3



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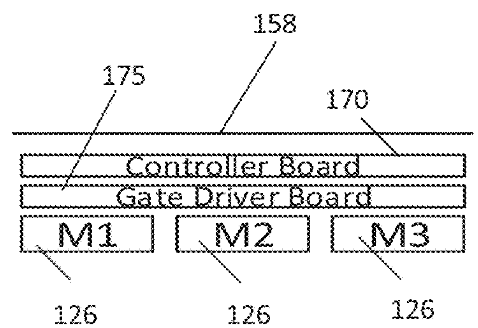

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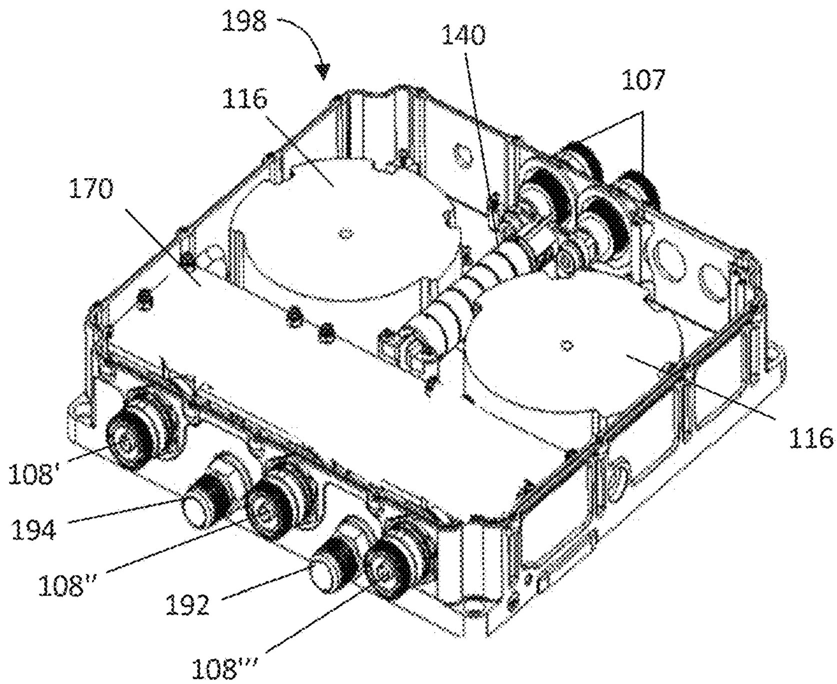

198
140
107
116
170
116
108'
194
108''
192
108'''

FIG. 7

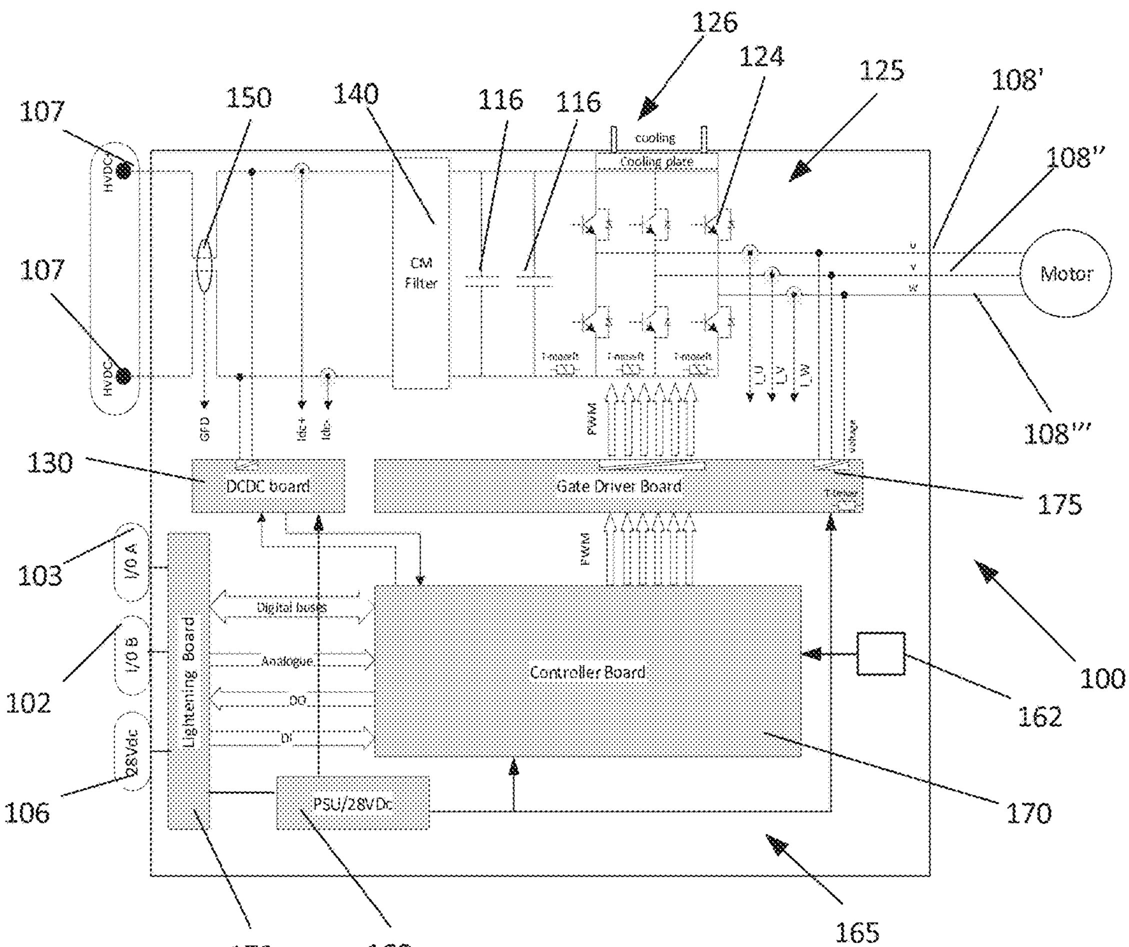

126
124
125
150
140
116
116
108'
107
108''
107
cooling
Cooling plate
HVDC+
HVDC-
CM Filter
Motor
GFD
Idc+
Idc-
PWM
IU
IV
IW
Voltage
130
DCDC board
Gate Driver Board
175
103
I/O A
Digital buses
Analogue
I/O B
DO
Controller Board
Lightening Board
DI
28Vdc
PSU/28VDc
102
106
162
100
170
108'''
165
170
160

FIG. 8

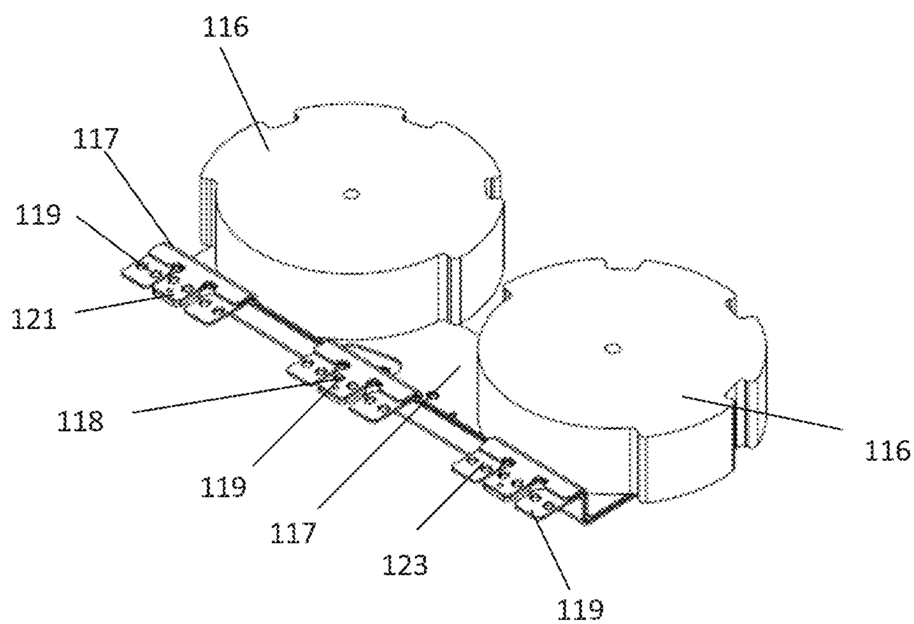


FIG. 9

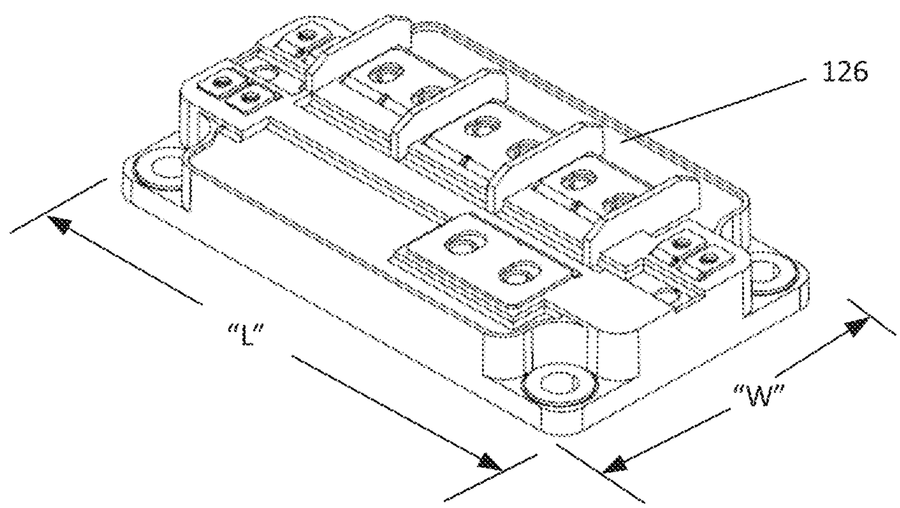


FIG. 10

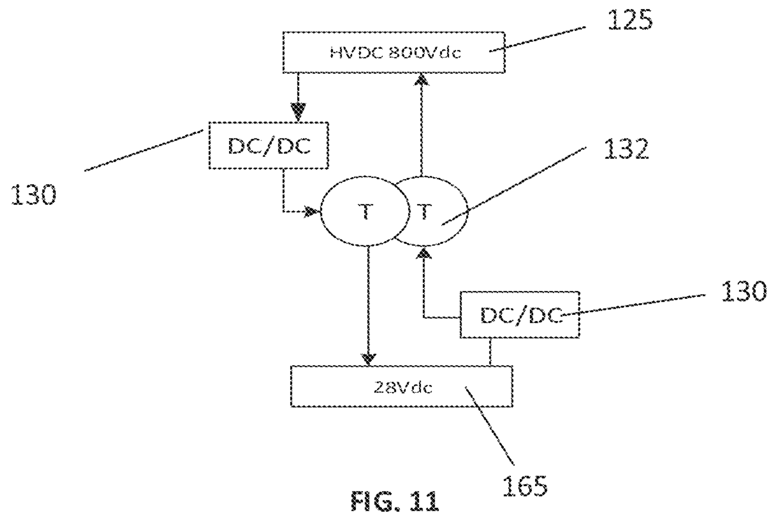

125
HVDC 800Vdc
DC/DC
130
132
T
T
DC/DC
130
28Vdc
165

FIG. 11

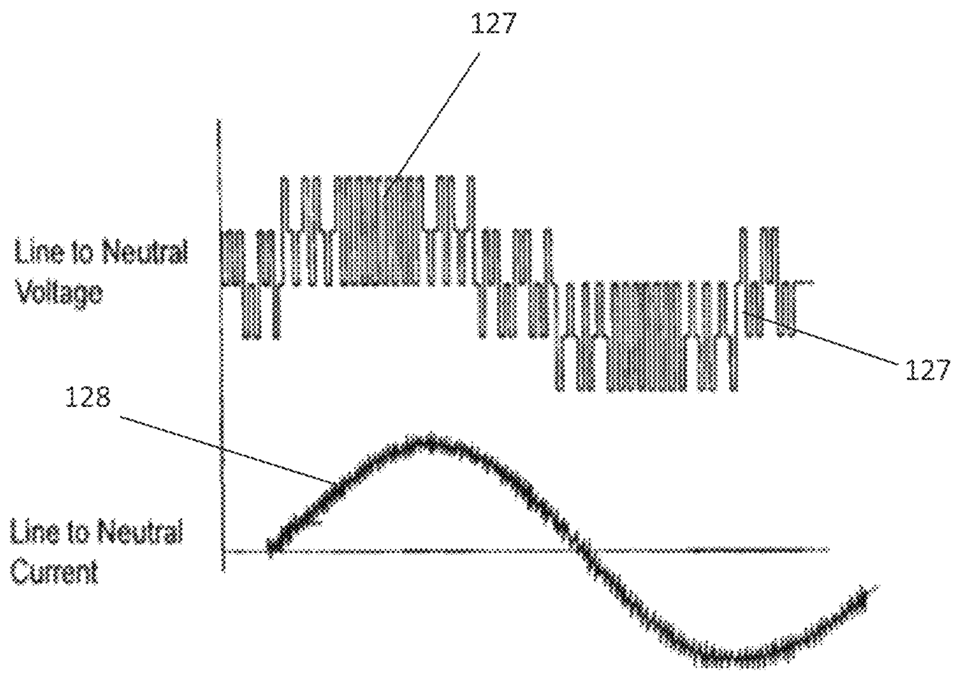

127
Line to Neutral Voltage
127
128
Line to Neutral Current

FIG. 12

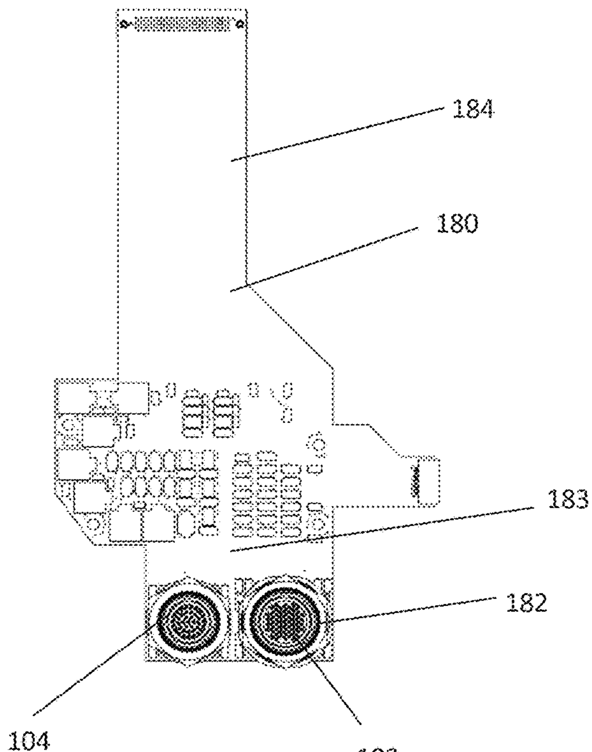


FIG. 13

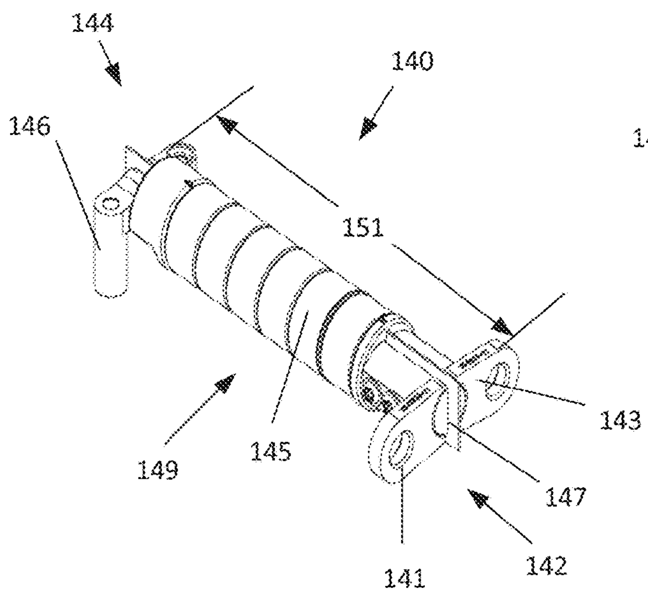


FIG. 14

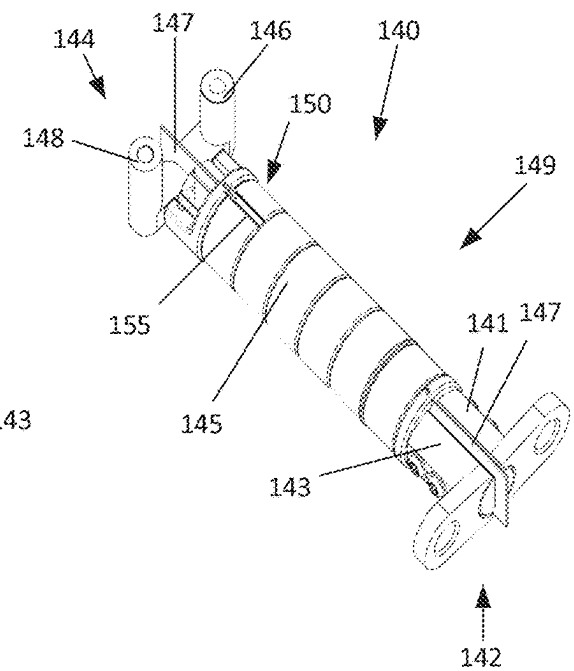


FIG. 15

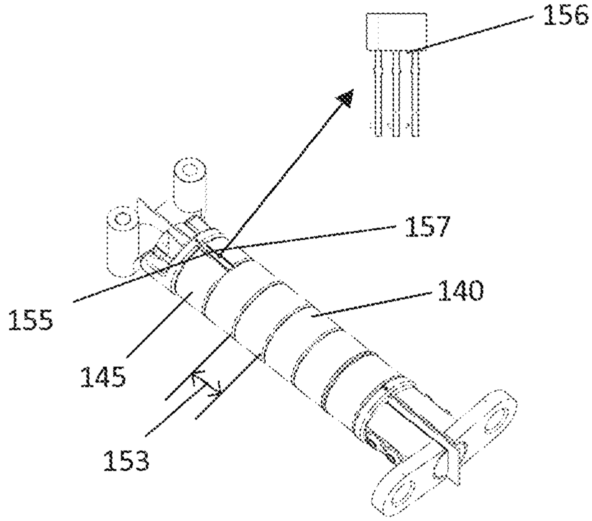


FIG. 16

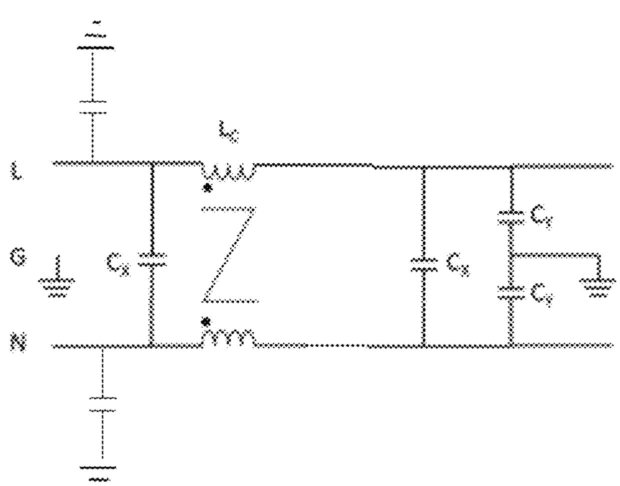
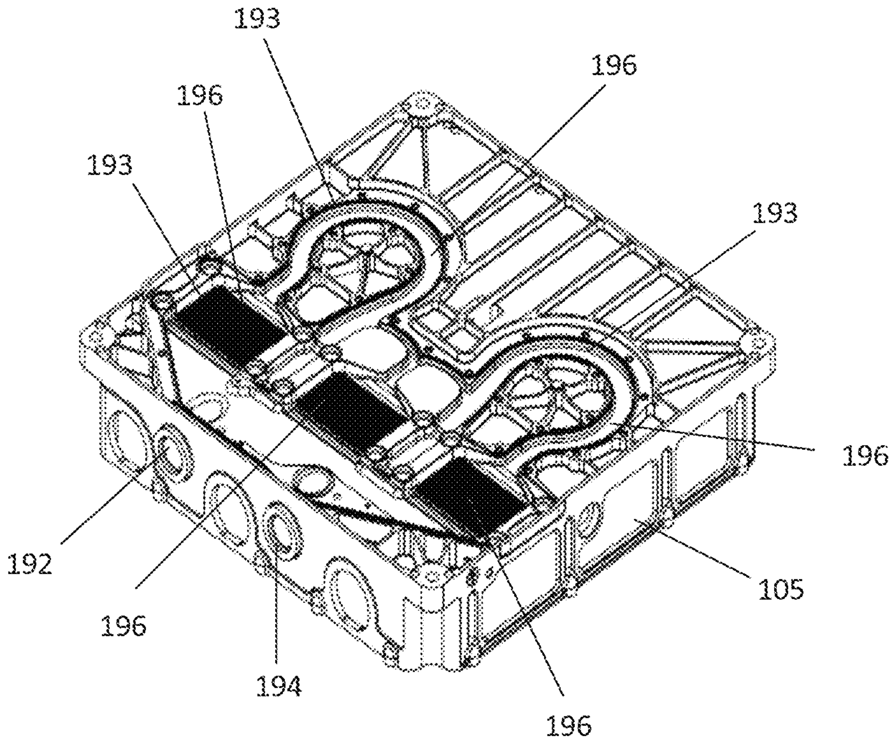


FIG. 17


193
196
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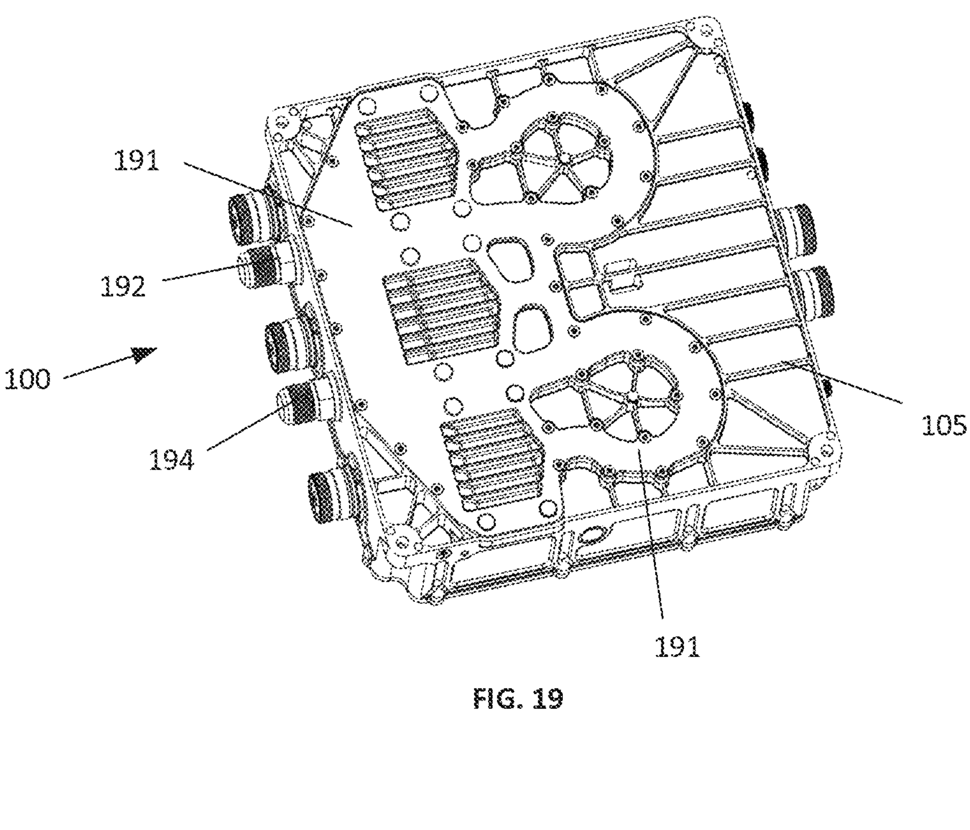
105
194
196

FIG. 18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191

FIG. 19

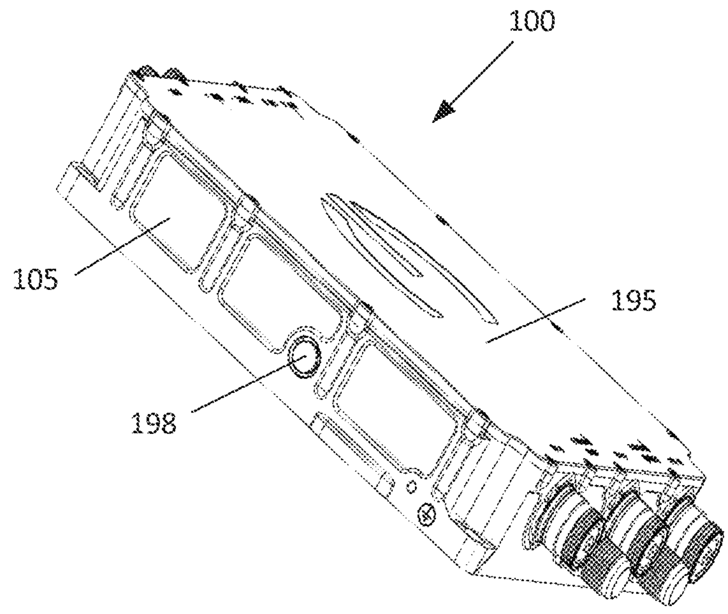

FIG. 20

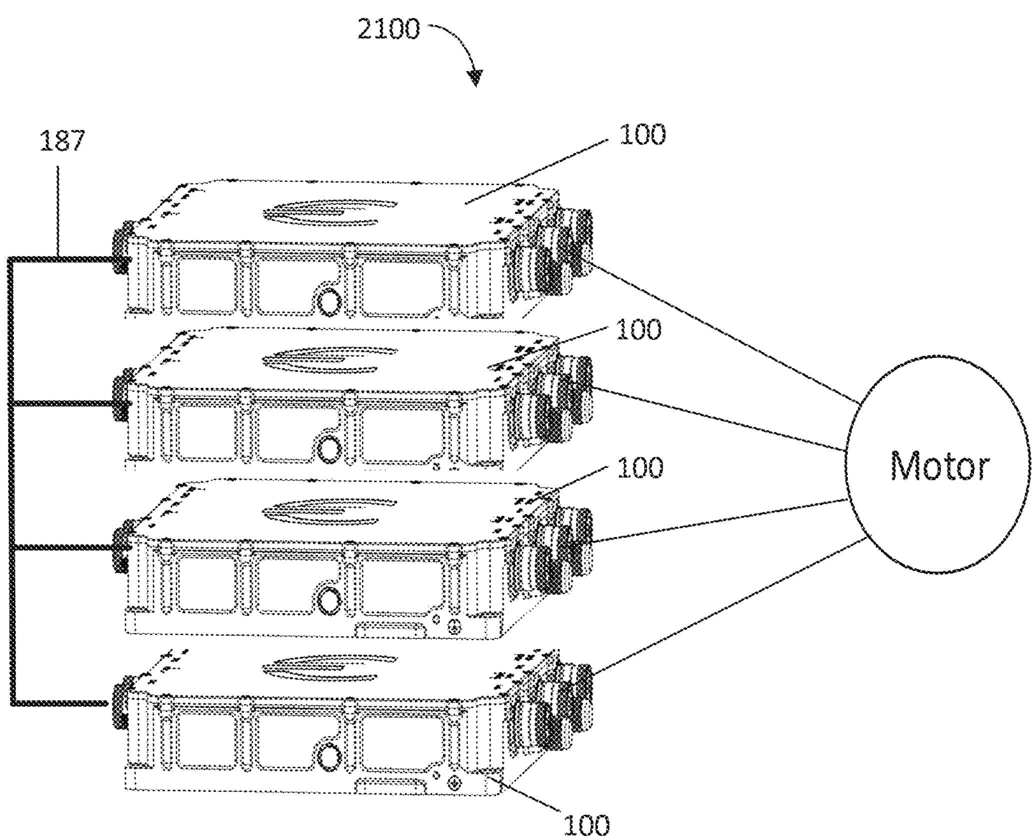

FIG. 21

HIGH VOLTAGE CONVERTER FOR USE AS ELECTRIC POWER SUPPLY

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 16/888,809, filed May 31, 2020, which claims the benefit of provisional U.S. Patent Application No. 62/855,143, filed on May 31, 2019; 62/855,147 filed on May 31, 2019; and 62/855,151 filed on May 31, 2019, the entire content and disclosure of which is incorporated herein by reference.

BACKGROUND

This disclosure relates to an electrical power supply system, including a high-power, high-voltage, multi-use converter/inverter for converting high-voltage, direct-current (HVDC) to high-power, preferably multiphase high-voltage, alternating-current (HVAC). The power supply systems can have multiple uses, such as, for example, as a motor controller to power electric motors for aircraft, preferably including manned aircraft, or as a power converter for converting alternating-current (AC) to high-power, high-voltage, direct-current.

There is a need for a light-weight, reliable, high-density, high-voltage, high-power electric power supply system for diverse applications, including, for example, to power electric motors, particularly for high load and/or high-torque situations, such as, for example, for use in electric powered aircraft, e.g., manned aircraft. There is a further need for a high-power density, high-efficiency, highly-reliable motor controller and electric power supply that exhibits high thermal, vibration, and electromagnetic interference (EMI) performance characteristics.

SUMMARY OF THE INVENTION

The summary of the disclosure is given to aid the understanding of an electric power supply system including a high-power, high-voltage converter/inverter and its method of operation, preferably to power and control an electric motor. The present disclosure is directed to a person of ordinary skill in the art. It should be understood that various aspects and features of the disclosure may advantageously be used separately in some instances, or in combination with other aspects and features of the disclosure in other instances.

In one or more embodiments, an electric power supply system to supply high-power, high-voltage, alternating-current (HVAC) is disclosed. The high-power electric power supply in one or more embodiments comprises circuitry adapted and configured to receive high-voltage, direct-current (HVDC) and convert the high-voltage, direct-current (HVDC) to high-power, preferably high-voltage, multiphase alternating-current (HVAC). The electric power supply includes a housing containing and protecting the circuitry, the housing having a plurality of input connectors to receive the high-voltage, direct-current (HVDC) and a plurality of output connectors to output the high-power, high-voltage, alternating-current (HVAC). The high-voltage, direct-current (HVDC) input to the power supply in an embodiment can be as low as from about 320 volts to as high as about 820 volts, more preferably about 480-750 Vdc. The power supply preferably has an output power of about 50 to about 160 kilowatts, with about 10 Volts RMS to about 350 Volts

RMS, and about zero to about 400 Amps RMS at a frequency range of about 10 Hertz (Hz) to about 1000 Hz. In an aspect the power supply has a power density of 10 kw per kg (kw/kg) or greater, preferably 14 kw/kg or greater. The electric power supply in an aspect is about 97% efficient or better, including about 98% efficient, or greater.

The electric power supply in an embodiment includes Silicon Carbide (SiC) MosFET power switches. Gate driver circuitry in an embodiment is used to drive the power switches. The electric power supply in one or more aspects include DC pre-charge capacitors that are pre-charged for operation, and are connected to and used as a power source for the power switches. The electric power supply in one or more embodiments incorporates an integrated EMI filter to protect against electromagnetic interference (EMI), the integrated EMI filter delivering HVDC input power to the DC capacitors. The EMI filter in an aspect includes ferrite rings surrounding the rail conductors and in an embodiment incorporating ground fault detection (GFD). In an embodiment, the GFD includes a sensing element, preferably a linear Hall-effect sensor, to detect leakage current escaping to ground, and in an embodiment includes a Hall-effect sensor incorporated into a gap in one of one or more ferrite rings surrounding the conductor rails delivering power to the DC pre-charge capacitors.

The electric power supply preferably further comprises low-voltage converter circuitry to convert the HVDC to low-voltage, direct-current (LVDC) of about 12 to about 50 volts direct-current, more preferably DC voltage as low as about 18 volts to as high as about 32 volts, and more preferably about 28 volts. The low-voltage converter circuitry or Power Supply Unit (PSU) in an embodiment is used to power the gate driver circuitry that drives the power switches and other, preferably all other, internal electronics boards contained within the power supply, including a controller board containing processors to monitor and control the electric power supply. The low-voltage converter circuitry optionally is further used to pre-charge HVDC capacitors. The electric power supply optionally further comprises a controller board having a processor and other ancillary circuitry to run monitoring software and hardware. The electric power supply can further comprise circuitry to read temperature and pressure sensor data. The housing of the electric power supply in one or more embodiments has input connectors communicating with the circuitry to read temperature sensor data. The housing of the electric power supply in one or more aspects further includes a cooling system, preferably a liquid cooling system incorporated within the electric power supply, and in an aspect integrated within the housing of the electric power supply. The cooling supply in an embodiment includes one or more coolant input connectors and one or more coolant output connectors, the one or more input connectors communicate with a flow path or channel through the power supply that communicates with the one or more coolant output connectors, the coolant input connectors and flow path configured and adapted to receive liquid coolant. The housing in an embodiment includes a vent to equalize pressure between the interior and the exterior of the housing.

In one or more embodiments, a multiuse motor controller is disclosed, the multiuse motor controller including circuitry adapted and configured to receive high-voltage, direct-current (HVDC) and convert the HVDC to high-power, high-voltage, alternating-current (HVAC) or to receive high-voltage alternating-current (HVAC) and convert the HVAC to high-power, high-voltage, direct-current (HVDC); and a housing containing and protecting the circuitry, the housing having a plurality of input connectors to receive the HVDC or HVAC and a plurality of output connectors to output the high-power HVDC or high-power HVAC. The multiuse motor controller preferably uses the same hardware and control to generate HVDC from HVAC as to generate HVAC from HVDC. The multiuse motor controller in an aspect produces HVAC power of about 50 to about 160 kilowatts, and has a power density of about 10 kw per kg or greater, preferably 14 kw/kg or greater. The multiuse motor controller or power supply optionally further includes circuitry and software to provide protection and monitoring of at least one of the group of short circuit, over-current, over-voltage, ground fault detection, temperature, and combinations thereof.

A motor controller system is also disclosed where the system has a plurality of electric power supplies or motor controllers, preferably a plurality of high-power electric power supplies or motor controllers, wherein each power supply or motor controller is modular and scalable. In one or more aspects, multiple, multiphase power supplies, e.g., dual, multi-phase motor controllers, can be incorporated into a single housing that preferably uses a single integrated cooling system. In an aspect, the motor controller system is configured and adapted to be operable if one or more of the power supplies or motor controllers is inoperable, downgraded, and/or faulty.

BRIEF DESCRIPTION OF THE DRAWINGS

The various aspects, features, and embodiments of the electric power supply system, e.g., voltage converter/inverter, and its method of operation will be better understood when read in conjunction with the figures provided. Embodiments are provided in the figures for the purpose of illustrating aspects, features, and various embodiments of the electric power supply system, e.g., the electric voltage converter/inverter, and its operation, but the disclosure should not be limited to the precise arrangement, structures, assemblies, subassemblies, systems, features, aspects, circuitry, functional units, embodiments, methods, processes, or devices shown, and the arrangement, structure, assembly, subassembly, system, features, aspects, circuitry, functional units, embodiments, methods, processes, and devices shown may be used singularly or in combination with other arrangements, structures, assemblies, subassemblies, systems, features, aspects, circuitry, functional units, embodiments, details, methods, processes, and/or devices.

FIG. **1** shows a top front perspective view of an embodiment of an electric power supply system, e.g., a voltage converter/inverter, for use in an aspect as, for example, an electric motor controller.

FIG. **2** shows a front side view of the electric power supply system/motor controller of FIG. **1**.

FIG. **3** shows a back perspective view of the electric power supply system/motor controller of FIG. **1**.

FIG. **4** shows a back side view of the electric power supply/motor controller of FIG. **1**.

FIG. **5** shows a block diagram representation of a top view of the electric power supply system/motor controller of FIG. **1** with the top cover plate removed.

FIG. **6** shows a block diagram representation of a cross-section view of the power supply/motor controller taken along line **6-6** of FIG. **5**.

FIG. **7** shows a top perspective view of the electric power supply system/motor controller of FIG. **1** with the top cover plate, lightening board, and DC-DC converter board removed.

FIG. **8** shows a schematic representative block diagram of an embodiment of the functional units and their interconnections in the electric power supply/motor controller of FIG. **1**.

FIG. **9** shows an example embodiment of the DC capacitors and bus bar used to power the power switches in the electric power supply/motor controller of FIG. **1**.

FIG. **10** shows an example embodiment of the power module containing power switches used in the electric power supply/motor controller of FIG. **1**.

FIG. **11** shows a block diagram schematic representation of an example DC-DC converter board used in the electric power supply/motor controller of FIG. **1**.

FIG. **12** shows the output voltage and current of the electric power supply/motor controller of FIG. **1**.

FIG. **13** shows an example lightening board used in the electric power supply/motor controller of FIG. **1**.

FIG. **14** shows a top perspective view of an example integrated EMI Filter and Ground Fault Detection Unit used in the electric power supply/motor controller of FIG. **1**.

FIG. **15** shows a bottom perspective view of the example integrated EMI Filter and Ground Fault Detection Unit of FIG. **14**.

FIG. **16** shows an exploded representation of an embodiment of the Ground Fault Detection Unit incorporated in the EMI Filter of FIGS. **14-15**.

FIG. **17** shows a schematic representation of the EMI Filter in the power supply/motor controller of FIG. **1**.

FIG. **18** shows a bottom perspective view of an example housing of the electric power supply/motor controller of FIG. **1** illustrating an example liquid cooling system.

FIG. **19** shows a bottom perspective view of an example housing and bottom cover plate for the liquid cooling system used in the electric power supply/motor controller of FIG. **1**.

FIG. **20** illustrates a side perspective view of a vent in the housing of the electric power supply/motor controller of FIG. **1**.

FIG. **21** illustrates a front perspective view of an embodiment of multiple electric power supply systems, e.g., voltage converts/inverters, for use in a system for supplying and controlling electric power to, for example, one or more electric motors.

DETAILED DESCRIPTION

The following description is made for illustrating the general principles of the invention and is not meant to limit the inventive concepts claimed herein. In the following detailed description, numerous details are set forth in order to provide an understanding of a power-supply, its architectural structure, components, and method of operation, particularly configured as a motor controller for electric motors, however, it will be understood by those skilled in the art that different and numerous embodiments of the power supply, its architectural structure, methods of operation, and uses may be practiced without those specific details, and the claims and invention should not be limited to the arrangements, structures, embodiments, assemblies, subassemblies, features, functional units, circuitry, processes, methods, aspects, features, details, or uses specifically described and shown herein. Further, particular features, aspects, functions, circuitry, details, and embodiments described herein can be used in combination with other described features, aspects, functions, circuitry, details, and/or embodiments in each of the various possible combinations and permutations.

Unless otherwise specifically defined herein, all terms are to be given their broadest possible interpretation including meanings implied from the specification as well as meanings understood by those skilled in the art and/or as defined in dictionaries, treatises, etc. It should also be noted that, as used in the specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless otherwise specified.

FIGS. **1-8** show an electric power supply system **100** configured to convert/invert high-voltage, direct-current (HVDC) of about 320 to about 820 dc volts, preferably about 480 to about 750 dc volts, and more preferably about 500 to about 650 dc volts, to high-voltage, alternating-current (HVAC), preferably high-power, HVAC. The electric power supply system **100** in one or more embodiments outputs a multiphase HVAC that varies between 0 volts and about 0.61 to about 0.78 times the HVDC voltage in terms of root mean squared (RMS) voltage when measured line to line between phases. More specifically, the multiphase HVAC varies between 0 volts and about 0.707 times the HVDC voltage input in terms of fundamental root-mean-squared (RMS) voltage when measured line to line between phases when the controller is employing a Space Vector Pulse Width Modulation (SVPWM) scheme. In one or more embodiments for example, the electric power supply **100** outputs about 50 to about 160 kilowatts (power) having about 10 to about 350 volts RMS and about zero to about 400 amps RMS of alternating current, preferably multi-phase alternating current. Each phase of the preferred multi-phase alternating-current ranges from 10 Hertz (Hz) to as high as 1000 Hz, with a preferred operational (non-surge) range of about 10 to about 720 Hz.

In a further aspect, the electric power supply **100** additionally converts high-voltage, alternating-current (HVAC) to high-voltage, direct-current (HVDC), preferably high-power, HVDC. In one or more embodiments, the electric power supply converts high-voltage, alternating-current to HVDC of about 50 to 160 kilowatts having direct-current of about 10 to about 400 amps and a voltage range of about 320 to about 820 volts. The electric power supply **100** in one or more embodiments has one or more circuits and/or components for converting the HVAC to HVDC. In one or more embodiments, the same hardware and control can be used and applied to generate high-voltage, alternating-current from direct-current, or vice versa regenerate high-voltage, direct-current from alternating-current.

The electric power supply system **100**, also referred to as a converter or inverter, is in one or more embodiments configured as an electric motor controller **100**. While the electric power supply system **100** is configured and described for use as a motor controller **100** for supplying and regulating power to an electric motor it should be appreciated that the power supply system **100** and/or features, aspects, teaching, and methods disclosed herein can have multiple additional and/or alternative applications, and that the electric power supply system **100** is not limited to powering electric motors. The disclosed electric power supply system **100** has features and advantages beneficial to electric power supply systems for use in electric motors for aviation applications, and particularly aircraft, e.g., manned aircraft, applications, as well as other aviation, aerospace and automotive applications, however, the power supply, converter/inverter, and/or motor controller and its features will be applicable to other applications.

The electric power supply system **100**, e.g., motor controller, of FIGS. **1-8**, in addition to converting high-voltage, DC (HVDC) to high-voltage, alternating-current (HVAC), preferably high-power HVAC, regulates the alternating-current delivered to the electric motor in terms of timing, magnitude, and frequency. The motor controller **100** in one or more aspects regulates the alternating-current delivered to the electric motor, direction of rotation, and the rotational speed of the electric motor. The output alternating-current (AC) is regulated by the motor controller **100** to control torque and/or limit output speed of the electric motor. In one or more embodiments, the output alternating-current varies from about zero to about 400 amps RMS, at a frequency from 10 Hertz (Hz) up to 1000 Hz, with a non-surge operating range of about 10 to about 720 Hz. The regulation of the AC output of the motor controller, and the regulation of the connected electric motor or electric motor module, is achieved by regulating the duty cycle and timing of the output current of the motor controller relative to the angular position of the back-EMF voltage vector of the connected electric motor. The control of electric motors, e.g., Permanent Magnet Synchronous Machines, is generally known to those skilled in the art.

The motor controller **100**, e.g., the electric power supply, is configured and packaged for delivering high-power of about 10 to 160 kilowatts, more preferably about 50 to 160 kilowatts, and with a power density of about 10 kw/kg or greater, preferably 14 kw/kg or greater, while being highly efficient, and achieving low electromagnetic interference (EMI) susceptibility and emission. The phrase about 10 kw/kg or greater is intended to cover power density that may be less than 10 kw/kg, but in proximity to 10 kw/kg, and power densities that are equal to or greater than 10 kw/kg. The housing **105** of the motor controller **100** could suitably be constructed from either a conductive metal, e.g., aluminum, or composite aircraft structural material, e.g., carbon fiber, with an integral conductive shield and meets lightning strike protocols for the aviation industry, such as, for example, B4 designation from RTCA DO-160G Section 22. In one or more embodiments, the power (motor) controller **100** meets the DO160 standard. In an embodiment, the high-power electric power supply **100**, e.g., motor controller, is tightly packaged providing high-density power, and light-weight in a low-volume package. The motor controller **100** in an embodiment is packaged in a housing **105** that measures about 328-333 mm in length, about 335-340 mm in width, and about 70-80 mm in height, and weighs about 11.0 to about 11-12 kg, more preferably about 11.8 kg, including with the coolant, while delivering upto about 160 kilowatts of power.

The power density is preferably achieved with EMI protection, e.g., high EMI resistance and immunity, and cooling systems, e.g., heat exchangers, so that the motor controller **100** operates within stable temperature zones. The motor controller **100**, e.g., the electric power supply, has high thermal, EMI, and vibration performances and stability. The motor controller **100**, e.g., the electric power system, in one or more embodiments includes high cooling performance, including, in examples a liquid cooling system. The power controller **100** is highly efficient with low power loses, e.g., low voltage rise time (overvoltage spikes) dV/dt of about 16 kV/μs or less. The motor controller **100** preferably has lightening protection up to the B4 waveform given by the test procedure in Section 22 of RTCA DO160G. In one or more embodiments, the power (motor) controller **100** meets the environmental requirements from the RTCA DO-160G Environmental Conditions and Test Procedures for Airborne Equipment standard, particularly the categories concerning performance at altitude, with temperature variation, conducted and radiated emissions (EMC/EMI), and vibration.

FIGS. **1-3**, and **7-8**, shows the power supply housing **105** with two (2) high-voltage, direct-current (HVDC) input connections **107**. In one or more embodiments, the power supply **100** receives HVDC of about 320 volts to about 820 volts, more preferably about 480 volts to about 650 volts, with direct-current of about 200 amps up to about 400 amps. The high-voltage, direct-current (HVDC) supplied to the motor controller **100** in one or more embodiments can be supplied by one or more high-voltage, direct-current batteries (not shown), although other sources for the high-voltage, direct current (HVDC) are contemplated. In one or more embodiments, the motor controller **100** converts the input power, e.g., high-voltage, direct-current (HVDC) to multiphase high-voltage, alternating-current (HVAC) output power, preferably multi-phase, high-power HVAC output. In one or more embodiments, the motor controller outputs three-phase, high-voltage, alternating-current. As shown in FIGS. **3-4** and **7-8**, the power supply/motor controller housing **105** has three (3) alternating-current output connectors **108**, one for each phase of output alternating-current, e.g., **108'**, **108"**, and **108'"**. The motor controller preferably produces high-power HVAC and delivers to each connector **108'**, **108"**, and **108'"** high-voltage of up to 820 volts, more preferably 800 volts, and alternating-current of about 100 to about 400 amps at a frequency of 10 Hz up to about 1,000 Hz. In one or more embodiments, there are current and voltage sensors in the motor controller **100** on the input and output sides. The input and output current and voltage sensors monitor and regulate the input and output power conditions, e.g., the voltage and current conditions.

In addition to the HVDC inputs **107** and HVAC outputs **108**, the motor controller **100** has one or more inlet (**192**) and outlet (**194**) connectors **109** for coolant ingress into and egress out of the motor controller housing **105** as shown in FIGS. **3-4** and described further in connection with the cooling system **190** as shown more clearly in FIGS. **18-19**. Preferably, the motor controller **100** uses liquid coolant for the purposes of transferring heat from the power switches, DC capacitors, and associated circuitry, as well as other circuitry, and preventing unacceptable temperatures and temperature rise in the motor controller circuits and components during operation as described in more detail below. The motor controller **100** also preferably includes internal temperature sensors, and also includes internal temperature monitoring hardware. In an embodiment, as shown in FIGS. **1-2**, the motor controller **100** has input connectors **102** for control and sensor inputs for use by the control and monitoring software in the motor controller **100**. The motor controller **100** preferably includes circuitry to read and convert signals from external temperature sensors (such as may be mounted in the motor or in sub-modules elsewhere in the system) for use by the control and monitoring software in the motor controller **100**. The power supply **100**, in one or more embodiments, has an input communication and sensor connection **103** that can be configured to communicate with a separate system controller if present (not shown). In this manner, the motor controller **100** receives an input signal from a system controller and controls the resulting torque by adjusting the HVAC output that is supplied by the motor controller **100** to the electric motor or other electrical appliance. The power supply or motor controller **100** in one or more embodiments has an input communication and sensor connection **104** that is configured to receive one or more input signals from an electric motor (not shown). Input connectors **104** receive various control inputs from, for example, the aircraft, feedback from the electric motors or loads, and/or other systems, e.g., other motor controllers, cooling systems, and/or the system controller, to monitor operations, and to control and regulate its HVAC output. The motor controller **100** in one or more embodiments identifies and manages fault conditions that arise within the motor controller **100**, and in aspects faults within the electric motor or electric motor module.

As shown in FIGS. **1-2** and **8**, the power supply **100**, e.g., the motor controller **100**, in an embodiment, includes a low-voltage, direct-current (LVDC) input connector **106** for receiving low-voltage, direct current (LVDC) to power the electronics as explained in more detail below. The LVDC input preferably is about twelve (12) to about fifty (50) volts, preferably about eighteen (18) to about thirty-two (32) volts, more preferably about twenty-eight (28) volts. The motor controller **100** optionally contains additional DC-DC converter circuitry **130** that converts the high-voltage DC (HVDC) from the HVDC power inputs **107** to low-voltage DC (LVDC) that is used to power the auxiliary and control circuitry as will be explained in greater detail below. In an embodiment, the DC-DC converter circuitry **130** preferably is included in the motor controller **100** as a redundant power source for the control and monitoring features of the motor controller **100** by converting the HVDC input of about 400-820 volts, more preferably about 480-650 volts, to about twelve (12) to about fifty (50) volts, preferably about eighteen (18) to about thirty-two (32) volts, more preferably about twenty-eight (28) volts to power the low-voltage circuits **165**.

The motor controller **100** in one or more aspects has high-voltage circuitry **125** as shown in FIG. **8** for converting the HVDC input **107** to multiphase HVAC output **108** to power an electric appliance (e.g., an electric motor), and low-voltage circuitry **165** to power the auxiliary and control electronics controlling and managing the high-voltage circuitry as well as handling the system monitoring as will be explained in more detail below. The power supply/motor controller **100** includes a number of subsystems, functional units, assemblies, and/or circuitry configured to perform different functions as will be explained in more detail below. As shown in FIGS. **5-8** the motor controller **100**, in one or more embodiments, includes DC capacitors **116** with a bus bar **117**, power modules **126** containing power (transistor) switches **124**, DC-DC converter circuitry board **130**, an EMI filter **140**, Ground Fault Detection (GFD) unit **150**, EMI shielding **158**, Power Supply Unit (PSU) **160**, controller board **170**, gate driver board **175**, lightening board **180**, and cooling system **190**. In one or more embodiments, the motor controller **100** converts the input HVDC power, e.g., high-voltage of about 320-820 volts (more preferably about 480-650 volts) and about 100-400 amps, to multiphase high-voltage, alternating-current (HVAC) output power of about 50 to about 160 kilowatts at up to about 850 volts, more preferably about 820 volts, and about 100 to 400 amps RMS at a frequency from about 10 Hz to about as high as 1,000 Hz, and more preferably in a normal (non-high-load) range of about 10 Hz to about 720 Hz.

In a preferred embodiment, the power supply/motor controller **100** includes a multi-phase voltage source inverter circuitry portion **125** shown in FIG. **8**. The inverter section **125**, preferably high-voltage inverter circuitry section **125**, of the motor controller **100** has circuitry and/or components that convert the DC input power **107**, e.g., the high-voltage DC input power **107**, to multiphase AC output power **108**, preferably a multiphase high-power, high-voltage, alternating-current, preferably to power an electric motor for example for manned aircraft applications. The high-voltage inverter circuitry **125** includes, in one or more embodiments, Ground Fault Detection **150**, an Electro-Magnetic Interference (EMI) filter **140**, DC capacitors **116**, and power modules **126** containing power switches **124** to convert the HVDC to HVAC. In one or more embodiments, the inverter circuitry **125** can also be used to convert HVAC to HVDC.

In a preferred embodiment, the power supply, e.g., the motor controller **100**, contains one or more DC capacitors **116** as shown in FIGS. **5** and **7-9** to provide the required HVDC power to the power modules **126**/power switches **124**. The motor controller **100** uses DC capacitors **116** to provide power to the power switches **124** because the DC capacitors **116** permit rapid voltage change and power delivery required by the power switches **124**, and serve as decoupling between the load (e.g., the electrical appliance/electric motor) and power source networks (e.g., high-voltage battery system). The DC capacitors **116** each have a capacitance of about 100 micro-Farads to about 400 micro-Farads, more preferably about 250-300 micro-Farads, for a total capacitance of about 200 micro-Farads to 800 micro-Farads, more preferably about 500 micro-Farads. In addition, the capacitors **116** have a voltage rating of about 100 to about 850 volts, more preferably about 750 volts to handle the HVDC. Moreover, since the capacitors **116** are for storing high-voltage and require high-reliability, their structure and construction is about 800 cm^3 each. Each DC capacitor **116** has a height of about 60 mm to about 65 mm, and a radius of about 100 mm to about 110 mm. While the motor controller **100** illustrates as shown in FIGS. **5** and **7-9** using two DC capacitors **116** in parallel, it should be appreciated that one capacitor, or more than two capacitors in parallel, may be utilized to perform the function of powering the power switches **124**.

Bus bar **117** as shown in FIG. **8** receives HVDC power input **107** from the EMI filter **140**, or optionally from the DCDC converter circuitry **130**. The middle connector **118** of bus bar **117** as shown in FIGS. **7** and **9** receives HVDC that is delivered to the two DC capacitors **116**, while each outboard connector **121**, **123** receives the output from one of the capacitors **116**, with the outboard connectors **121**, **123** connected to, and which provide power (voltage and current) to, the power modules **126** containing the power switches **124**. The bus bar **117** is positioned in proximity to and preferably adjacent to the power modules **126** containing power switches **124**. More specifically, the bus bar **117** has three pads **119** that form connections to and from the DC capacitors **116**. Each pad **119** receives two electrical connections. The middle connector **118** is spaced about 25 mm to about 30 mm from the out-board connectors **121** and **123**. The bus bar **117** electrical connections and pathways are formed of conductive material, preferably aluminum, separated by insulting material, preferably flexible insulating material, forming a laminar bus bar.

Motor controller **100** as shown in FIGS. **6**, **8** and **10** uses power (transistor) switches **124**, preferably Silicon Carbide (SiC) MosFETs, to convert the HVDC to HVAC, preferably high-power, multiphase HVAC. The motor controller **100** uses power switches **124**, preferably Silicon Carbide MosFETs, for higher switching speed and reduced power losses. This reduction in power losses facilitates higher current capacity of about 400 Amps RMS in the switches **124** and increases the power density of the motor controller **100**. The power switches **124**, e.g., the SiC MosFets **124**, are highly efficient providing less switching power losses. Each power switch **124** permits a rapid rise in voltage. The combination of multiple power switches **124** output multiphase HVAC **108**, and more particularly three power switch modules **126** each containing two power switches **124** are configured to output three phases of HVAC **108'**, **108"**, and **108'''**, where each power module **126** produces one phase of HVAC **108**. The motor controller **100** in an embodiment utilizes gate driver circuitry **175** to drive the power switches **124** based on the switching states output by the motor control software and hardware primarily contained on controller board **170**. The gate driver circuitry **175** drives the six power switches **124** with different timing so that each power module **126** is 120 degrees out-of-phase from the other power modules **126**. For example, if power module **126'** produces HVAC **108'** at zero degrees (no phase shift), then power module **126"** produces HVAC **108"** at a 120 degree later phase shift, and power module **126'''** produces HVAC **108'''** at a 240 degrees later phase shift.

Each power module **126** has two power switches **124**, e.g., two Silicon Carbide (SiC) MosFets, one switch (MosFet) **124** configured to produce current in one direction and drive one half (½) of the HVAC output, the other power switch **124** configured to produce current in the other direction and drive the other half of the HVAC output, where both power switches (e.g., MosFets) **124** in the power module **126** together produce the HVAC output **108**. The gate driver circuitry **175** triggers the two MosFet switches **124** in each power module **126** in a manner to produce the HVAC. Each power switch **124** receives triggering pulses from the gate driver circuitry **175** and HVDC. Each power module **126** as shown in FIG. **10** has a length "L" of about 105 mm to about 110 mm, a height "h" of about 60 mm to about 65 mm, and a width "W" of about 90 mm to about 95 mm, and weighs about 215 to about 225 grams, more preferably about 220 grams. The power modules **126** are rated for a maximum current of about 400 Amps RMS, and power of about 50 kw for this particular motor controller application (high-power output), but it should be appreciated that different rating could be used for different applications. It should also be appreciated that this example of motor controller **100** is designed to produce three (3) phase HVAC, and more or less power switches **124** and power modules **126** could be used for single phase, dual phase, or greater than three phase HVAC output operation, where the gate driver circuitry **175** would trigger the power switches **124** appropriately. More information on driving the power switches **124** will be provided when describing the gate driver circuitry **175** and the controller board **170**.

The DC-DC converter circuitry or DCDC board **130** in an aspect performs a pre-charge function for the DC capacitors **116**. When a voltage source is connected to the motor controller **100** it is highly desirable to have a current limiting function that enables the DC capacitors **116** to be safely charged to a voltage that allows safe connection of the full DC link power from the HVDC input connectors **107**. That is, before the HVDC input power **107** is applied to the DC capacitors **116**, they are pre-charged to, or nearly to, the voltage level of the HVDC input power **107**, so that the full HVDC input power **107** can be applied to the motor controller **100**. In the current state of the art, this current limiting functionality is typically implemented outside the motor controller. The motor controller **100** according to one or more embodiments incorporates low-voltage circuitry into the motor controller **100** to pre-charge the DC capacitors **116** by incorporating the pre-charge circuitry for the DC capacitors **116** into the motor controller **100** thereby decreasing overall weight associated with the electric power supply **100**.

In one or more embodiments, the DC-DC converter board **130** as shown in FIGS. **5**, **8**, and **11** receives LVDC from the low voltage circuitry **165**, preferably but not necessarily from PSU **160**, and steps-up the voltage to HVDC to pre-charge the DC capacitors **116**. In one or more embodiments, the DC-DC converter board **130** is supplied LVDC, e.g., twelve (12) to fifty (50) volts, preferably about eighteen (18) to about thirty-two (32) volts, more preferably about twenty-eight (28) volts DC. The DC-DC converter board **130** pre-charges the DC capacitors **116** to, or nearly to, the voltage level of the HVDC input **107**. In this regard, in one or more embodiments, the DC-DC converter board **130** is implemented using a DC boost circuit that is added to the onboard DC-DC converter to step-up the LVDC to HVDC. The DC boost circuit converts the LVDC, for example about eighteen (18) to about thirty-two (32) volts, preferably 28 volts DC, to a higher voltage, in this application about 500 volts to 850 volts, more preferably to a voltage level equal or comparable to the voltage from HVDC input **107**, in order to charge the DC capacitors **116** to comparable voltage levels in order to minimize the inrush current when the full DC voltage from HVDC input **107** is connected to the motor controller **100**, and the motor. In an aspect, the DCDC converter board **130** utilizes one or more transformers **132** to step-up the voltage from LVDC to HVDC to pre-charge the DC capacitors **116**. The DCDC converter board **130** pre-charges the DC capacitors **116** during start-up before the motor controller receives HVDC power.

After the DC capacitors **116** are charged to the voltage level, or to a comparable voltage level, of the HVDC input **107**, or within a threshold of the HVDC input **107**, the DC voltage from the DC-DC converter board **130** is no longer utilized, and, in an aspect, the DC-DC board **130** isolates from the HVDC circuit **125**. After the DC capacitors **116** are pre-charged to the voltage level of the HVDC input **107**, and during operation of the high voltage circuitry **125** to produce high-power, HVAC output **108**, for example during operation of the power switches **124**, the DCDC converter board **130** and voltage step-up circuitry no longer charges the DC capacitors **116**. As the threshold pre-charge voltage level is reached, the DCDC converter circuitry **130** in an embodiment is disconnected and/or disabled and the HVDC power source is connected.

In one or more embodiments, the DCDC board **130** also optionally produces LVDC from the HVDC input **107** on the high-voltage (HV) circuit side **125** of the motor controller **100**. In one or more embodiments, the motor controller **100** has a Power Supply Unit (PSU) **160** which is supplied LVDC from LVDC input **106**, and optionally in an embodiment can receive LVDC produced from DCDC converter board **130**, in an aspect, in the event that the LVDC power source to connector **106** should fail. In one or more embodiments, the motor controller **100** detects that the LVDC supply is interrupted and the DC to DC converter circuitry **130** is activated to generate LVDC from the HVDC input power. That is, DCDC converter board **130** can receive HVDC from power inputs **107** and step down the HVDC from the high-voltage circuit side **125** to supply PSU **160**, and/or power the control, monitoring, and auxiliary circuit boards with LVDC. In one or more embodiments, the one or more transformers **132** in the DCDC converter board **130** used to step-up the LVDC to pre-charge the capacitors **116**, can be used to step-down the voltage from the HVDC input power **107** to LVDC used to power the PSU **160**, and/or the various control and monitoring circuits, e.g., controller board **170** and gate driver board **175**. In this manner, the DCDC converter board **130** can serve as a redundant power source to supply LVDC to circuitry **165**, and in an example embodiment serve as a power source for the PSU **160**.

The DCDC converter board **130** preferably steps the HVDC down to between twelve (12) and fifty (50) volts, preferably between about eighteen (18) to about thirty-two (32) volts, more preferably down to about 28 volts, and serves as a potential local LVDC generator to power the low voltage circuitry **165** including the controller board **170**. The dual functions of the DCDC converter board **130** are schematically illustrated in FIG. **11** where there is a LVDC input bus of 28 Vdc to the DCDC converter board **130** and the corresponding DC capacitor pre-charge output, and HVDC bus input to DCDC converter board **130** and corresponding local 28 Vdc output. The DCDC converter circuitry **130** also provides galvanic insulation between the HVDC circuitry **125** and the LVDC circuitry **165**. The transformer used to step-up and step-down the voltage insulates the high-voltage and low-voltage circuitry by providing mechanical, physical, and electrical segregation between both the HVDC and LVDC sides.

The PSU **160** shown in FIG. **8**, in one or more embodiments, supplies LVDC to the controller board **170**, the gate driver board **175**, and/or the DCDC converter board **130**. The PSU **160** in an embodiment is located on controller board **170**. The controller board **170** serves as the brain of the motor controller **100**. The controller board **170** contains processors and ancillary circuitry to run the electric appliance, e.g., electric motor, to run the control and monitoring functions and software, to communicate with other motor controllers **100**, and, if configured, to communicate with a system controller. The controller board **170** performs internal temperature monitoring from one or more internal sensors **162** (e.g., temperature sensors **162**), and contains the circuitry to read and convert signals from external temperature sensors (such as may be mounted in the motor) for use by control and monitoring software. The controller board **170** can receive other sensor and monitoring inputs, such as, for example, inputs from one or more motors and/or internal current and voltage sensors, to control the motor controller **100** and detect faults. The controller board **170** is mounted outboard of the DC capacitors **116** as shown in FIGS. **5-6**.

The controller board **170** also controls the gate driver board **175** and more specifically provides the timing to the gate driver board **175** to trigger the power switches **124** on and off. More specifically the gate driver board **175** acts as an actuator for the power switches **124** by providing a trigger, e.g., a voltage signal, to the gate of each of the power switches **124** to turn on the power switches **124** and permit current to flow. When the gate receives a trigger, e.g., a voltage signal, the voltage quickly rises to the level of the HVDC applied to the power switch **124** from the HVDC circuitry **125** and current flows through the power transistor (e.g., SiC MosFet) **124**. More particularly, the controller board **170** provides the timing regarding when and for how long the gate of the power switch **124** is triggered, e.g., the pulse width modulation (PWM) that the gate driver circuitry **175** provides to the power switches **124**. FIG. **12** shows the power output **108** of one phase of the motor controller **100** with the voltage pulses **127**, e.g., square waves **127**, and alternating current **128**, e.g., sinusoidal wave **128**, produced by the power switches **124**. Each power output **108'**, **108"**, **108'"** preferably has the same output as shown in FIG. **12**, just phase shifted 120 degrees. The controller board **170** provides the timing for the gate driver board circuitry **175** to trigger each power switch **124** in each of the three power modules **126** to produce the three-phase HVAC output of the motor controller **100**. That is, the controller board **170** provides the timing of six (6) signals, one signal to each gate of each power switch **124** so that each power module **126** provides HVAC out-of-phase with the other power modules **126**. It should be appreciated that if there were more or less power switches **124**, the gate driver board **175** would apply a triggering signal to each power switch **124** whose timing would be controlled by the circuitry and logic in the controller board **170** to produce HVAC as the output of the additional power module **126** and power switches **124**.

Motor controller **100** preferably includes an example lightening board **180**, as shown in FIGS. **5**, **8**, and **13**. The lightening board **180** receives the input signals **103** from the electric motor, and the input signals **104** from system sensors, or if applicable, a system controller. The lightening board **180** protects incoming signals from voltage or current spikes in the event of a lightening strike or other voltage or current spike. The lightening board **180** uses one or more diodes to protect against the incoming signals having a voltage or current spike. The lightening board **180** extends from the input connectors **102** (**103** and **104**) at the front side of the motor controller housing **105** to the controller board **170** at the back of the housing **105**. The lightening board **180** as seen in FIG. **13** includes a first portion **182** of the board **180** containing the input signal connectors **102** at a right angle to a second portion **184** of the board that extends to the controller board **170**. The lightening board **180** contains a flexible portion **183** to provide a right angle between the first portion **182** and second portion **184** of the printed circuit board (pcb) **180** for packaging purposes in the motor controller housing **105**.

Another optional feature of the power supply, e.g., motor controller **100**, is a highly integrated common mode EMI noise suppression filter **140** and ground fault detection (GFD) **150**. The input common mode EMI filter **140** is used to avoid and/or reduce electromagnetic interference (EMI) and/or electromagnetic conductance (EMC). In an aspect, the EMI filter **140** protects the HVDC power source from conducted EMI. As shown in FIGS. **5**, **7**, and **14-17**, the EMI filter **140** receives HVDC power at its front end **142** from connectors **107** and delivers the input power to the power bus bar **117** and in particular to the middle connector **118** of the bus bar **117**. The back end **144** of the EMI filter **140** contains two feet **146**, **148** which each rest on and connect to the middle connector **118** of the bus bar **117**. The EMI filter **140** contains two conductors or rails **141**, **143** shaped as half cylinders that are isolated from each other by insulation **147**. It will be appreciated that the rails **141**, **143** and insulator **147** can configured into and form different shapes. The insulator **147** is sufficient to protect against a short between the two rails **141**, **143** carrying the HVDC. The conductors **141**, **143** and insulator **147** are configured to be able to handle the high-power, e.g., the high-voltage and current, to be input to the motor controller **100**. The two conductor rails **141**, **143** and insulator **147** form a round shaft portion **149** that extends between the front end portion **142** and the back end portion **144** of the EMI Filter **140** and delivers the HVDC power from the input connectors **107** to the bus bar **117**.

Surrounding the shaft portion **149** of the EMI filter **140** are one or more ferrite rings **145** that suppress EMI. In an embodiment, there are a plurality of ferrite rings **145**, for example six (6) ferrite rings **145**, that surround the shaft portion **149** of the EMI filter **140** and suppress EMI. In an embodiment as shown in FIGS. **14-16**, the ferrite rings **145** enclose or surround the majority of the length **151** of the shaft **149** of the EMI Filter **140**, and in an aspect surrounds substantially the entire shaft length **151**. In an aspect, a small portion of the shaft portion **149** is not surrounded by the ferrite rings **145** to permit leads to connect to the controller board **170**. The EMI Filter **140** has a length **151** of approximately 160 mm to approximately 165 mm, the conductor rails **141**, **143** and insulator **147** combined have a diameter of approximately 18 mm, and the ferrite rings **145** each have an outer diameter **152** of about 29 mm, and inner diameter of about 18 to about 19 mm to permit the conductors **141**, **143** to pass through, and each ferrite ring **145** has a length **153** of approximately 14 to approximately 16 mm. While six (6) ferrite rings are shown and used in the example EMI filter **140**, it should be appreciated that more or less ferrite rings may be utilized, including a single ferrite ring, and the outer diameter **151**, the inner diameter, and the length **153** of each ferrite ring **145** can vary. The EMI filter **140** is used to cutoff common mode noises going to the source power. The ferrite rings **145** have a total inductance that in combination with the capacitance in the capacitors on the DCDC converter board **130** that is in proximity to the EMI filter **140** provides a sufficient low pass filter to cut off the common mode current. The structure of the EMI filter **140** utilizes CLC topology where the inductance from the ferrite rings **145** combines with the capacitance from the capacitors on DCDC converter board **130** in proximity to the ferrite rings **145** to cover all of the frequency spectrum defined by the DO160-G: LHM standard, (e.g., 150 kHz to 30 MHz). A representative circuit of the inductance of the EMI filter **140** and the capacitance coupling is shown in FIG. **17**. In the example embodiment of the EMI Filter **140** the total inductance of the plurality of ferrite rings **145** is about 35-70 micro-Henrys, more preferably about 45-50 micro-Henrys and the total capacitance on the DCDC converter board **130** in proximity to the ferrite rings **145** is about 1-5 micro-Farads, more preferably about 2 micro-Farads.

The Ground Fault Detection (GFD) unit **150** in an embodiment is integrated with the EMI filter **140** and mounted in the same bus bay as the EMI Filter **140**. The GFD unit **150** prevents ground faults and in an aspect incorporates a sensing element **155** to determine if there is leakage of current to ground. Detecting whether there is current leakage to ground in one or more embodiments is achieved by summing the positive and negative current leakage from the DC rails **141** and **143** and triggering an alert if a threshold on the leakage current is exceeded. In one or more embodiments, the sensing element **155** is one or more Hall effect sensors **156** that measure the current, and in an aspect one or more linear Hall effect sensors **156** are integrated with and configured in a gap **157** in one or more of ferrite rings **145** forming the EMI filter **140** as shown in FIG. **16**. The signals from the sensing elements, e.g., the linear Hall effect sensors, are transmitted to the leads on the shaft portion **149** of the EMI Filter **140**, and from the leads are transmitted to and received by the controller board **170** where the information from the sensing element(s) **155** are processed. The integrated EMI filter **140** and GFD **150** is light weight weighing about 415 to about 425 grams, more preferably about 420 grams and takes up low volume of about 160 mm×30 mm×30 mm.

The motor controller **100** further optionally includes EMI shielding **158** illustrated in FIG. **6** which is a thin sheet formed of metallic material, for example a foil, and which acts as a Faraday cage to prevent electro-magnetic emissions from escaping the motor controller **100**. The EMI shielding **158** is preferably located in proximity to the HVAC portion of the high-voltage circuitry **125**, including in proximity to the HVAC output **108** and power modules **126** connected to the HVAC output **108**.

The power supply/motor controller **100** in one or more embodiments includes a cooling system **190**, preferably a liquid cooling system to keep the temperature of the circuits and components within a desirable temperature range and prevent a rapid temperature rise inside the housing **105**. The cooling system **190** is formed on the underside of the housing **105** as shown in FIG. **18** and has an underside cover plate **191** as shown in FIG. **19**. The underside cover plate **191** forms a liquid seal with the housing **105** to retain the liquid coolant from leaking. There are no seams or seals to leak inside the compartment **198** of the motor controller housing **105** that contains the electronics and circuits, e.g., the high-voltage circuits **125** or low-voltage circuits **165**. The liquid coolant in one or more embodiments is silicon or turbine oil, although other fluids are contemplated as appropriate coolants. The cooling system has an inlet **192** for coolant, a winding conduit or channel **193** for the coolant to traverse, and an outlet **194**. The volume of the channel **193** within the housing **105** is about 300 ml to 500 ml for an example motor controller **100**, with the volume increasing to about 600 ml to 1 liter for a double sized motor controller described herein.

The coolant in an embodiment enters through inlet **192**, traverses the channel **193**, and exits the outlet **194** under 2.5 to 6 bars of pressure with a pressure drop of about 600 mbars. The material forming the common wall or surface **196** separating the channel **193** from the inside compartment **198** of the housing **105** is preferably a good heat conductor, for example aluminum. The channel **193** is formed in the housing **105** to run under the power modules **126** and DC capacitors **116** to assist with cooling the components in the motor controller, preferably the high-voltage, high-power circuitry **125**. That is, the coolant preferably flows under the DC capacitors **116** and power modules **126**. In an embodiment, channel **193** would form a near loop under the DC capacitors **116**. In one or more embodiments, the housing of the capacitors **116** and/or the housing or encasing of the power switches **126** are formed of heat conductive material, and further are configured to increase and maximize contact with the common wall or bottom surface **196** of the motor controller housing **105**. The motor controller housing **105** includes a top cover plate **195** to cover and protect the components, circuits, and subassemblies of the power supply/motor controller **100**.

The housing **105** of the motor controller **100** also optionally includes vent **185** as shown in FIG. **20** to provide pressure equalization for the inside compartment **198** of the motor controller housing **105**. The vent **185** preferably provides a hydrophobic and oleophobic (oil-resistant) barrier while allowing pressure equalization. Vent **185** permits weight saving to the design and structure of the housing **105** as the housing **105** does not have to bear a significant pressure gradient between the inside compartment **198** of the housing **105** and the exterior of the housing **105**. In addition, since the pressure gradient is low between the inside and outside of the housing **105**, the connector sealing is low. While the vent **185** has no orientation restraints, the vent preferably should not be placed against a flat wall or other location that would restrict air flow.

In an embodiment, power supply/motor controller **200** may be a double unit that produces two groups or sets of multiphase HVAC, e.g., dual, multiphase, high-power, HVAC, in one housing **205**. That is, there are two sets of three-phase HVAC power outputs (six HVAC outputs altogether). In one or more embodiments, double unit motor controller **200** would have two sets of the circuitry described in connection with motor controller **100**, for example two high voltage circuits **125**, and two low voltage circuits **165**. In an embodiment, double unit motor controller **200** would have two sets of DC capacitors **116** (four capacitors **116**), two bus bars **117**, two sets of three power modules **126** (six power modules **126**), two DCDC converter circuits **130**, two EMI Filters **140**, two GRD units **150**, two PSUs **160**, two controller boards **170**, two gate driver boards **175**, two lightening boards **180**, and two separate cooling systems **190**. The housing **205** in an embodiment has a common interior wall segregating the inside chamber into two separate chambers each containing one of the two sets of circuits and components, one on each side of the housing, or in an alternative embodiment there is no interior wall separating the circuits and components. In an embodiment of the double unit motor controller **200** there can be one single cooling system with one single channel **293** that traverses the underside of the housing **205**.

In a preferred embodiment, the electric power supply, e.g., motor controller, has Silicon Carbide power switches, a power density of about 10 kw/kg or greater, preferably greater than 14 kw/kg or greater, has an efficiency of greater than 97% (preferably greater than 98%), advanced liquid cooling and thermal performance, stable performance at high altitude, operates in unpressurised environments, has a high level of hardware and software protection, and meets the requirements of RTCA DO178C Software Considerations in Airborne Systems and Equipment Certification and RTCA D0254 Design Assurance for Airborne Electronic Hardware. Power Supply/motor controller specifications:

Efficiency	98%
Weight (Est.)	less than 12 kg/33 lbs
Interfaces	Digital communication bus CAN x2, RS485, temperature sensor PT1000, pressure sensors, rotor position RVDT Throttle Pressure sensors

In one or more embodiments, shown for example in FIG. **21**, multiple motor controllers **100** are used in a system **2100** to control and deliver high-power, multi-phase HVAC preferably to one or more electric motors or motor modules. The motor controllers **100** in an aspect are largely independent and are synchronized via their input torque commands. This ensures a high level of independence in the event of local failure of a motor segment or module of the motor, motor controller power section, or control software. The electric power supplies **100**, e.g., motor controllers, have a highly-modular, fault tolerant architecture providing a high level of redundancy and safety. The motor controllers **100** can use a high speed bus **187**, e.g., link(s), between the motor controllers **100** which controls and monitors the electric motor, or other apparatus or system that is supplied power. The high speed bus **187** can be used to transfer data, such as, for example, motor shaft positions and faults. The modularity and ability to use multiple motor controllers **100**, or one or more double unit motor controllers **200**, with redundant circuits, provides a level of redundancy and safety as faults can be isolated and the system **2100** (e.g., multiple motor controllers) can operate in degraded mode and remain operational.

An electric power supply is disclosed where the electric power supply includes a number of individual features and functions that may be employed individually or in combination. In an embodiment the electric power supply includes: high-voltage, direct-current (HVDC) circuitry comprising one or more DC pre-charge capacitors and one or more power transistor switches, the HVDC circuitry adapted and configured to receive high-voltage, direct-current (HVDC) input of about 320 volts and/or greater and convert the HVDC input power to multi-phase, high-voltage, alternating-current (HVAC) output power of about 230 volts and/or greater; low-voltage, direct current (LVDC) circuitry adapted and configured to operate on low-voltage, direct-current of about fifty volts and/or less, wherein the LVDC circuitry is configured to control and monitor the multi-phase HVAC output power. The electric power supply in one or more embodiments is further configured to receive multiphase, high-voltage, alternating-current (HVAC) input power of about 230 volts and/or greater and convert the multiphase HVAC input power to high-voltage, direct-current (HVDC) output power of about 320 volts and/or greater, preferably using the HVDC circuitry used to convert the HVDC input power to HVAC output power. In an aspect the electric power supply further includes DC to DC converter circuitry adapted and configured to receive and convert the low-voltage, direct-current to high-voltage, direct current of about 320 volts and/or greater to pre-charge the DC pre-charge capacitors. The DC to DC converter circuitry in an embodiment pre-charges the DC pre-charge capacitors during start-up and upon the DC pre-charge capacitors being charged to within a threshold of or to the HVDC input voltage, the DC to DC converter circuitry no longer charges the DC pre-charge capacitors. Another feature, the DC to DC converter circuitry is configured to not charge the DC pre-charge capacitors when the power transistor switches are operational. In a further aspect, the DC to DC converter is configured to receive and convert the HVDC input power to the low-voltage, direct current.

In a further embodiment the power transistor switches comprise Silicon Carbide MosFET power switches, and in an aspect two Silicon Carbide MosFET power switches are configured on a power module and each power module is configured to produce one phase of the multi-phase HVAC output. In a specific optional embodiment, the electric power supply has three power modules and the HVDC circuitry is configured to produce three-phases of HVAC output wherein each power module produces one phase of HVAC output and each power module is configured to shift its HVAC output from the other power modules. The electric power supply can include gate driver circuitry to trigger the power transistor switches.

The HVAC circuitry in one or more embodiments of the electric power supply further includes an EMI filter, the EMI filter having two electrically insulated rails configured and adapted to receive the HVDC, wherein the two electrically insulated rails have ferrite material at least partially surrounding the two rails. The EMI filter in an optional embodiment incorporates a ground fault detection unit. The ground fault detection unit in an embodiment includes a hall-effect sensor, and in an aspect the hall-effect sensor is positioned in a gap in the ferrite material and is configured to measure current in the ferrite material. In a further embodiment the two electrically insulated rails in the EMI filter are configured as a shaft having a substantially circular cross-section, and the ferrite material is formed as one or more rings surrounding the shaft, and optionally the EMI filter incorporates a ground fault detection unit that comprises a hall-effect sensor wherein the hall-effect sensor is positioned in a gap formed in at least one of the one or more of the ferrite rings, and the hall-effect sensor is configured to measure current in the ferrite rings. In yet a further embodiment, the two electrically insulated rails of the EMI filter deliver the HVDC input power to a bus bar adjacent DC pre-charge capacitors to deliver HVDC input power to the DC pre-charge capacitors. The DC pre-charge capacitors in an aspect comprise two DC pre-charge capacitors and the EMI filter extends between the two DC pre-charge capacitors from input connectors to a bus bar to deliver HVDC input power to the DC capacitors. In an aspect the EMI filter has inductance of about 35 to about 70 micro-Henrys and is positioned in proximity to one or more capacitors having a capacitance of about 1 to about 5 micro-Farads to provide a low pass filter to cutoff common mode current.

The LVDC circuitry in the electric power supply in an embodiment further includes controller circuitry having a processor and other ancillary circuitry to run monitoring software. The controller circuitry optionally has circuitry to read temperature and pressure sensor data, and in an aspect the electric power supply has input connectors communicating with the controller circuitry to read temperature sensor data. The electric power supply in an embodiment further includes a housing to contain and protect the HVDC circuitry, the LVDC circuitry, and the DC to DC converter circuitry, as well as other components and circuits, where in an aspect the housing has one or more coolant input connectors and one or more coolant output connectors, the one or more input connectors connected to a flow path through the power supply that communicates with the one or more coolant output connectors, the coolant input connectors and flow path configured and adapted to receive liquid coolant. The electric power supply with the housing and liquid coolant in an embodiment is configured to have a power density of 10 kw per kg and/or greater, and in an aspect while producing 50 kilowatts of power and/or greater. The electric power supply in one or more embodiments is about 97% efficient or better, and has a reduced power loss for overvoltage spikes of about 16 kV/μs or less. The housing for the electric power supply in an embodiment further has a vent to equalize pressure between the interior and exterior of the housing.

The electric power supply in one or more embodiments is configured as a motor controller to power and control an electric motor. An electric power supply system is also disclosed that includes two or more electric power supplies where each power supply is modular and scalable. The electric power supply system in one or more embodiments includes a high-speed communication link between the two or more electric power supplies to communicate between the two or more electric power supplies. In a further aspect, the electric supply system is capable of operating if one or more of the electric power supplies is degraded, faulty, or inoperable. The electric power supply system in one or more embodiments is configured as a motor controller to power and control an electric motor.

With respect to the above description, it is to be realized that the dimensional relationship for the parts of the system includes variations in size, materials, shape, form, function and the manner of operation as would be known to one skilled in the art, and all equivalent relationships to those illustrated in the drawings and described in the specification are intended to be encompassed by the invention.

Those skilled in the art will recognize that the disclosed and illustrated electric power supply, voltage converter/inverter, and/or motor controller have many applications, may be implemented in various manners and, as such is not to be limited by the foregoing embodiments and examples, but it is intended to cover modifications within the spirit and scope of the invention. While fundamental and optional features of the invention have been shown and described in exemplary embodiments, it will be understood that omissions, substitutions, and changes in the form and details of the disclosed embodiments of the electric power supply, voltage converter/inverter and/or motor controller can be made by those skilled in the art without departing from the spirit of the invention. Any number of the features of the different embodiments described herein may be combined into a single embodiment. The locations of particular elements, for example, the electric power connectors, outputs, circuitry, etc., may be altered.

Alternate embodiments are possible that have features in addition to those described herein or may have less than all the features described. Functionality may also be, in whole or in part, distributed among multiple components, in manners now known or to become known. The discussion of any embodiment is meant only to be explanatory and is not intended to suggest that the scope of the disclosure, including the claims, is limited to these embodiments. In other words, while illustrative embodiments of the disclosure have been described in detail herein, it is to be understood that the inventive concepts may be otherwise variously embodied and employed, and that the appended claims are intended to be construed to include such variations, except as limited by the prior art.

In the claims, the term "comprises/comprising" does not exclude the presence of other elements, features, or steps. Furthermore, although individually listed, a plurality of means, elements, or method steps may be implemented by, e.g., a single unit, element, or piece. Additionally, although individual features may be included in different claims, these may advantageously be combined, and their inclusion individually in different claims does not imply that a combination of features is not feasible and/or advantageous. In addition, singular references do not exclude a plurality. The terms "a", "an", "first", "second", etc., do not preclude a plurality. Reference signs or characters in the disclosure and/or claims are provided merely as a clarifying example and shall not be construed as limiting the scope of the claims in any way.

We claim:

1. An electric power supply, the electric power supply comprising:

direct-current (DC) to alternating-current (AC) circuitry adapted and configured to receive DC power input having a DC input voltage of about 320 DC volts to about 820 DC volts and convert the DC power input to multi-phase, alternating-current (AC) power output that ranges from ten (10) Hertz to as high as a thousand (1000) Hertz,

wherein the DC to AC circuitry further comprises:

at least two DC capacitors; and

an electromagnetic interference (EMI) noise filter to suppress EMI noise, wherein the EMI noise filter comprises two, electrically insulated, conductive rails configured side by side as a linearly extending shaft having a length and a cross-section and adapted to receive the DC power input, ferrite material formed as one or more elements substantially circumscribing the two conductive rails and extending a majority of the length of the two conductive rails, and a current sensing element positioned in a gap in the one or more elements formed of ferrite material and configured to measure leakage current escaping to ground,

wherein the two electrically insulated, conductive rails of the EMI noise filter are physically located and extend lengthwise at least partially between the at least two DC capacitors and delivers the DC power input to the at least two DC capacitors.

2. The electric power supply of claim **1**, wherein the current sensing element comprises a hall-effect sensor.

3. The power supply of claim **1**, wherein the EMI noise filter delivers the DC power input to a bus bar for delivery of the DC power input to one or more DC capacitors.

4. The electric power supply of claim **1**, wherein the EMI noise filter has inductance of about 35 to about 70 micro-Henrys and is positioned in proximity to one or more capacitors having a capacitance of about 1 to about 5 micro-Farads to provide a low pass filter to cutoff common mode current.

5. The power supply of claim **1**, further comprising a housing to contain and protect at least the DC to AC circuitry, wherein the housing has a housing length in the same direction as a length of the two, electrically insulated, conductive rails of the EMI noise filter, wherein the length of the two, electrically insulated, conductive rails is approximately fifty percent of the housing length.

6. The electric power supply of claim **1**, further comprising low-voltage, direct current (LVDC) circuitry adapted and configured to operate on LVDC power of about fifty volts or less, wherein the LVDC circuitry is configured to control and monitor the multi-phase AC power output.

7. The electric power supply of claim **1**, wherein the DC to AC circuitry converts multiphase AC power input to direct-current (DC) power output.

8. A motor controller system comprising two or more electric power supplies of claim **1**, wherein each electric power supply is modular and scalable and delivers the multiphase, AC power output.

9. The motor controller system of claim **8**, further comprises a high-speed bus between the two or more electric power supplies to transmit data between the two or more electric power supplies, wherein the system is capable of operating if one or more of the electric power supplies is at least one of a group consisting of: degraded, faulty, inoperable, and combinations thereof.

10. An electric power supply, the electric power supply comprising:

direct-current (DC) to alternating-current (AC) circuitry comprising two or more DC capacitors electrically connected in parallel and one or more power transistor switches, the DC to AC circuitry adapted and configured to receive DC power input having a DC input voltage of about 320 to about 820 DC volts and a DC input current of about 100 to about 400 amps and convert the DC power input to multi-phase, alternating-current (AC) power output; and

low-voltage, direct current (LVDC) circuitry adapted and configured to operate on LVDC power of about fifty volts or less, wherein the LVDC circuitry is configured to control and monitor the multi-phase AC power output,

wherein the DC to AC circuitry further comprises an electromagnetic interference (EMI) noise filter to suppress EMI noise, wherein the EMI noise filter comprises two, electrically insulated, conductive rails configured side by side as a linearly extending shaft having a length and a cross-section and adapted to receive the DC power input, ferrite material formed as one or more elements substantially circumscribing the two conductive rails and extending a substantial majority of the length of the two conductive rails, and a current sensing element positioned in a gap in the one or more elements of ferrite material substantially circumscribing the two conductive rails and configured to measure leakage current escaping to ground, wherein the two electrically insulated, conductive rails of the EMI noise filter are physically located and extend at least partially between the two or more DC capacitors that are electrically connected in parallel and delivers the DC power input to the at least two or more DC capacitors.

11. The electric power supply of claim **10**, wherein the current sensing element comprises a hall-effect sensor.

12. The power supply of claim **10**, wherein the EMI noise filter delivers the DC power input to a bus bar for delivery of the DC power input to the one or more DC capacitors.

13. The electric power supply of claim **10**, wherein the EMI noise filter has inductance of about 35 to about 70 micro-Henrys and is positioned in proximity to one or more capacitors having a capacitance of about 1 to about 5 micro-Farads to provide a low pass filter to cutoff common mode current.

14. The power supply of claim **10**, further comprising a housing to contain and protect at least the DC to AC circuitry, wherein the housing has a housing length in the same direction as a length of the two, electrically insulated, conductive rails of the EMI noise filter, wherein the length of the two, electrically insulated, conductive rails is approximately fifty percent of the housing length.

15. The electric power supply of claim **10**, further comprising DC to DC converter circuitry configured to receive and convert the DC power input to the LVDC power and configured to receive and convert the LVDC power to DC power to pre-charge the DC capacitors.

16. The electric power supply of claim **10**, further comprising DC to DC converter circuitry to pre-charge the DC capacitors during start-up and upon the DC capacitors being charged to within a threshold of or to the DC input voltage, the DC to DC converter circuitry no longer charges the DC capacitors.

17. The electric power supply of claim **10**, wherein the power transistor switches comprise Silicon Carbide MosFET power switches and two Silicon Carbide MosFET power switches are configured to produce one phase of the multi-phase AC power output.

18. The electric power supply of claim **17**, comprising three power modules wherein each power module comprises two Silicon Carbide MosFET power switches and wherein the DC to AC circuitry is configured to produce three-phases of AC power output wherein each power module is configured to shift its phase of AC power output from the phase of the other power modules.

19. The electric power supply of claim **10**, wherein the multiphase AC power output ranges from ten (10) Hertz to as high as 1000 Hertz.

20. The electric power supply of claim **10**, further comprising a housing to contain and protect the DC to AC circuitry and the LVDC circuitry, wherein the housing further comprises a flow path through the power supply configured and adapted to receive liquid coolant, wherein the flow path communicates with one or more coolant inputs and one or more coolant outputs.

21. The electric power supply of claim **20**, wherein the power supply with the housing and liquid coolant has a power density of 10 kw per kg or greater.

22. The electric power supply of claim **10**, further comprising a connector for receiving an input signal to controls the AC power output.

23. The electric power supply of claim **1**, wherein the one or more elements of ferrite material substantially circumscribing the two conductive rails extend a substantial majority of the length of the two conductive rails.

24. The electric power supply of claim **1**, wherein the at least two DC capacitors are electrically connected in parallel.

25. The electric power supply of claim **1**, further comprising DC to DC converter circuitry to pre-charge the at least two DC capacitors during start up and upon the at least two DC capacitors being charged within a threshold of or to a DC input voltage, the DC to DC converter circuitry no longer charges the at least two DC capacitors.

26. The electric power supply of claim **1**, wherein the one or more elements of ferrite are configured as one or more rings, wherein the gap is formed in at least one of the one or more rings.

27. The electric power supply of claim **1**, wherein the DC power input has a DC current of about 100 amps to about 400 amps and a thickness of each of the two side by side conductive rails is greater than 1 mm.

28. The electric power supply of claim **1**, wherein the DC to AC circuitry comprises at least two separate circuits, each separate circuit adapted and configured to receive DC power input and convert the DC power input to the multi-phase, alternating-current (AC) power output, the electric power supply further comprising a high speed bus between the two circuits to transmit data between the two or more separate circuits, wherein the electric power supply is capable of operating if one or more of the electric power supplies is at least one of a group consisting of: degraded, faulty, inoperable, and combinations thereof.

29. The electric power supply of claim **6**, wherein the LVDC circuitry is configured to pre-charge the DC capacitors.

30. A motor controller system, the motor controller system comprising:

two or more electric power supplies; and

a high speed bus connected between the two or more electric power supplies to transmit data between the two or more electric power supplies, wherein each of the two or more electric power supplies comprises:

direct-current (DC) to alternating-current (AC) circuitry adapted and configured to receive DC power input having a DC input voltage and convert the DC power input to multi-phase, alternating-current (AC) power output,

wherein the DC to AC circuitry further comprises an electromagnetic interference (EMI) noise filter to suppress EMI noise, wherein the EMI noise filter comprises two, electrically insulated, conductive rails configured and adapted to receive the DC power input, ferrite material at least partially surrounding the two conductive rails, and a current sensing element positioned in a gap in the ferrite material and configured to measure leakage current escaping to ground; and

wherein each electric power supply is modular and scalable and delivers the multiphase AC power output; and

wherein the system is capable of operating if one or more of the electric power supplies is at least one of a group consisting of: degraded, faulty, inoperable, and combinations thereof.

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