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(54) **ELECTRONIC SYSTEMS FOR ELECTRIC VEHICLES AND RELATED METHODS**

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H02P 27/06	(2006.01)

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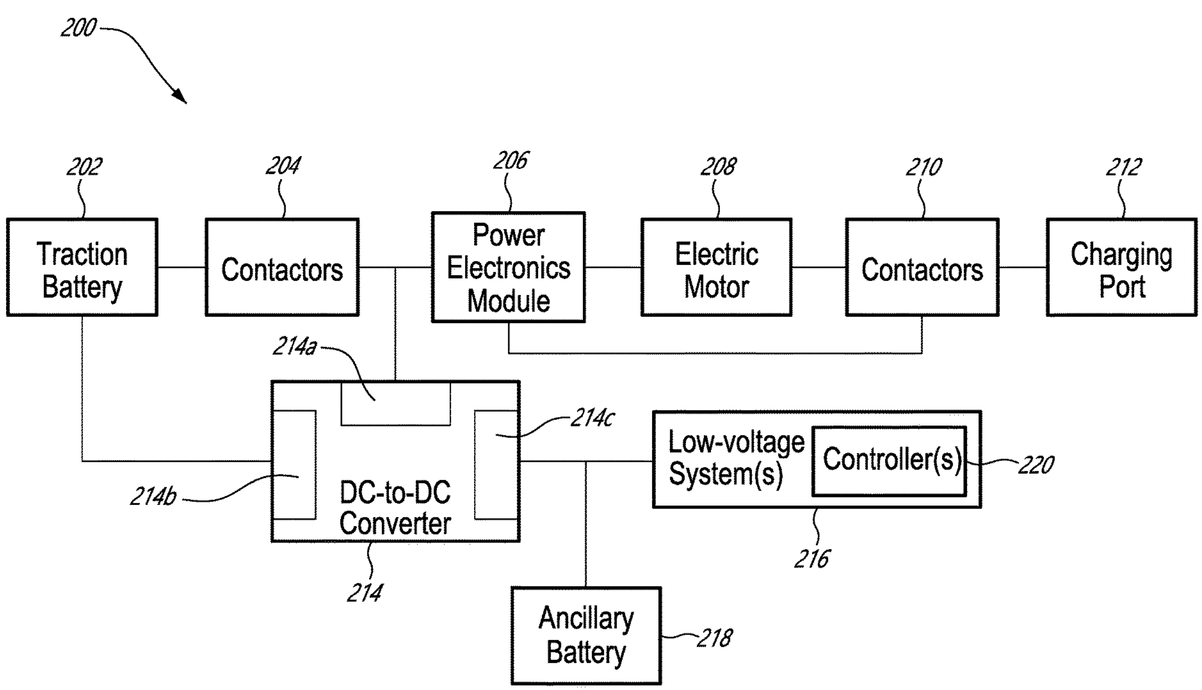
(57) **ABSTRACT**

Power electronics systems for electric vehicles are provided. These systems may enable propulsion and charging of an electric vehicle, among other functionalities. Related methods are also provided. According to an embodiment, a system includes a battery, a power electronics module to connect to the battery, an electric motor including a plurality of phase windings and a neutral point, and a port to connect to an external device. Each of the plurality of phase windings may connect between the power electronics module and the neutral point. The port may include a first terminal and a second terminal. The system may also include at least one electrical switch to selectively connect the first terminal of the port to the neutral point of the electric motor and to selectively connect the second terminal of the port to the power electronics module.



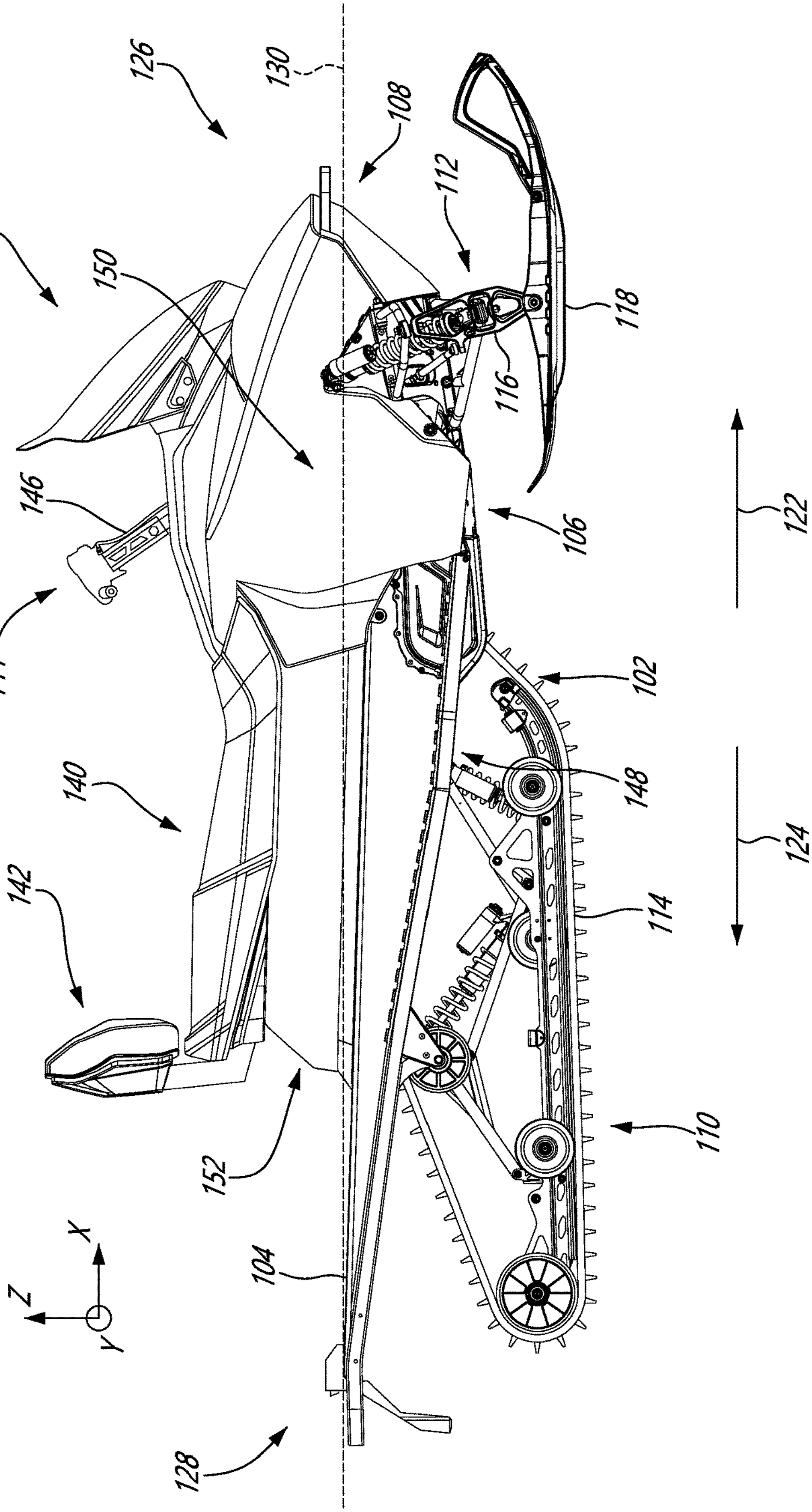

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FIG. 1A

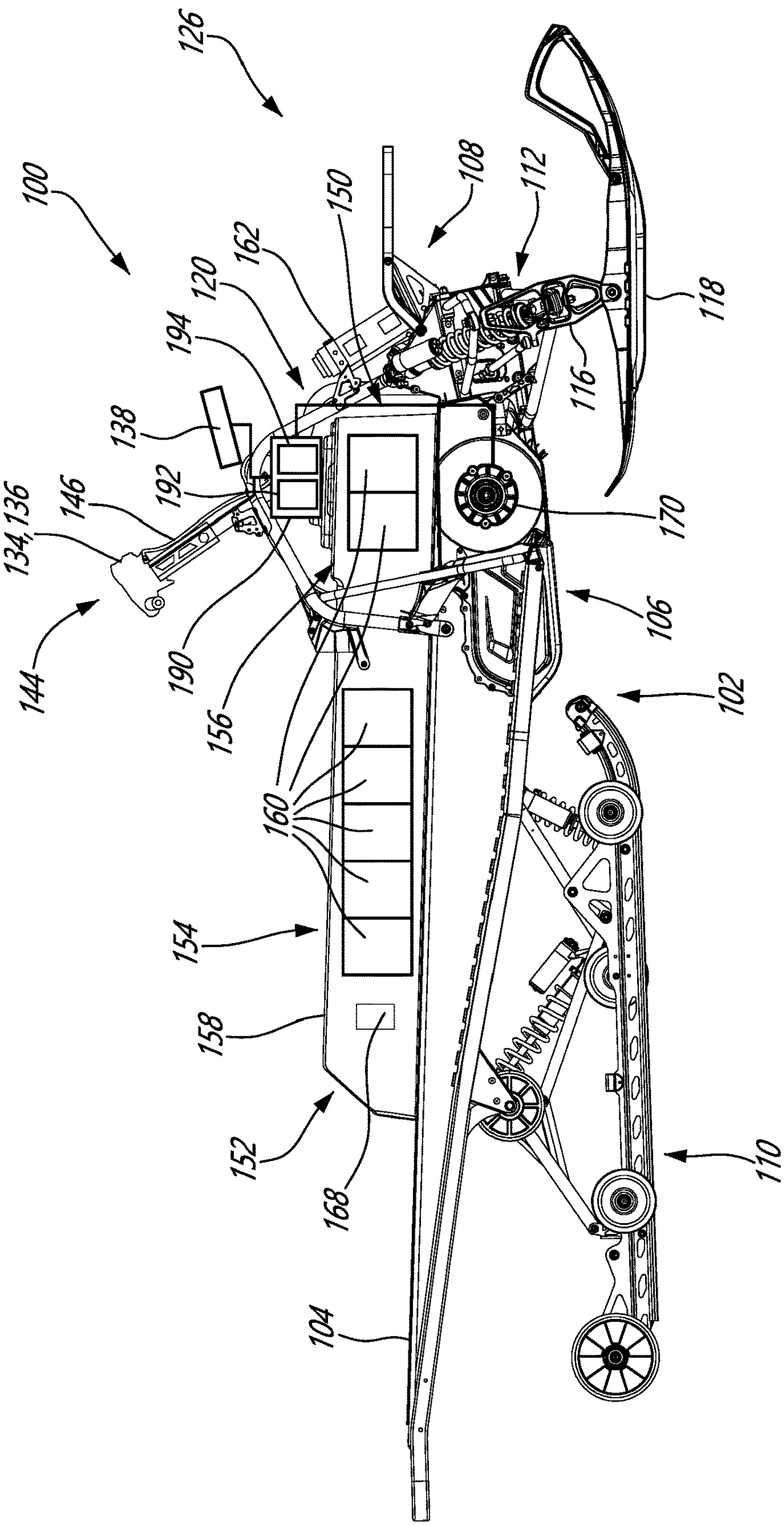
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FIG-1B

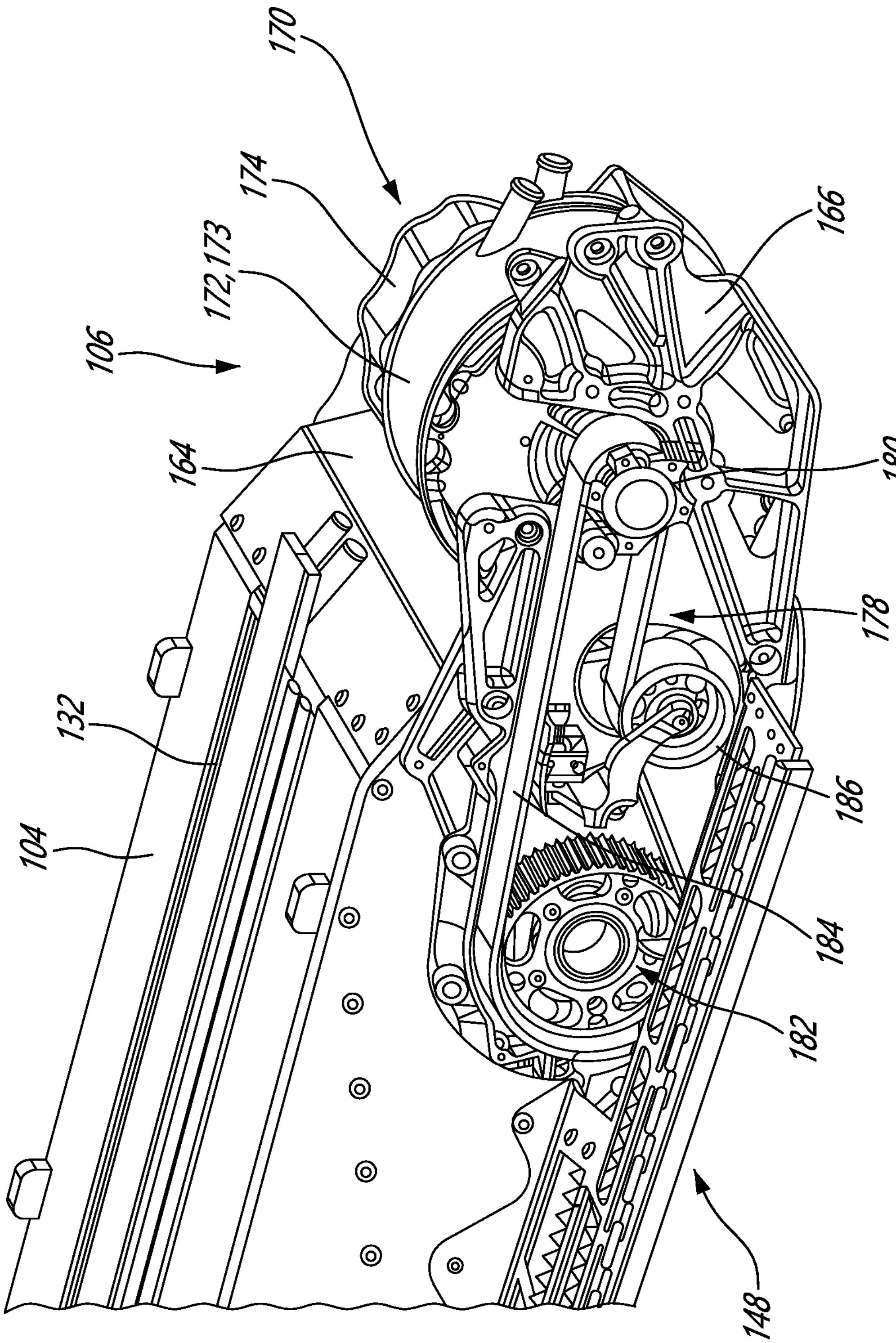


FIG-3

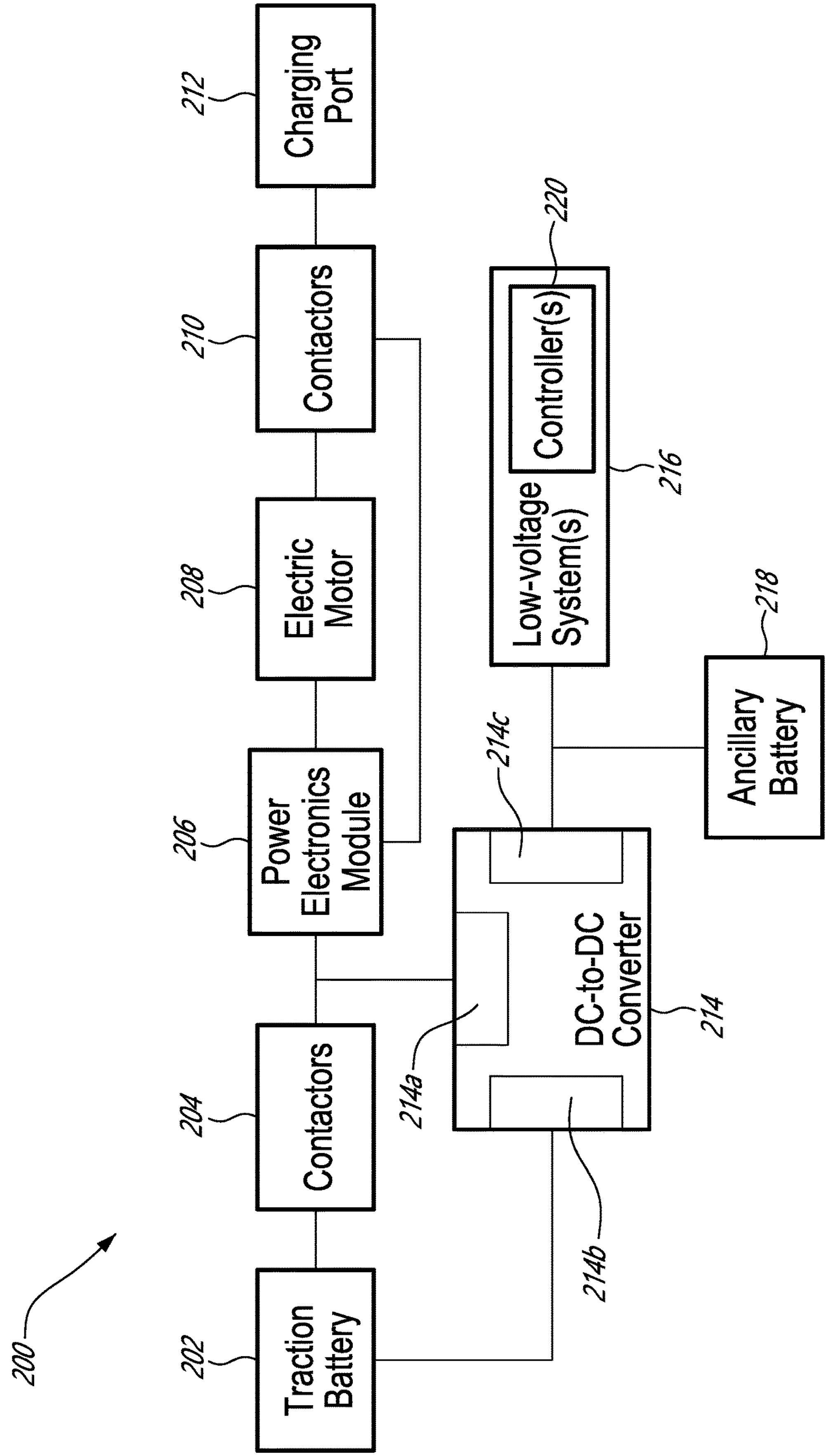
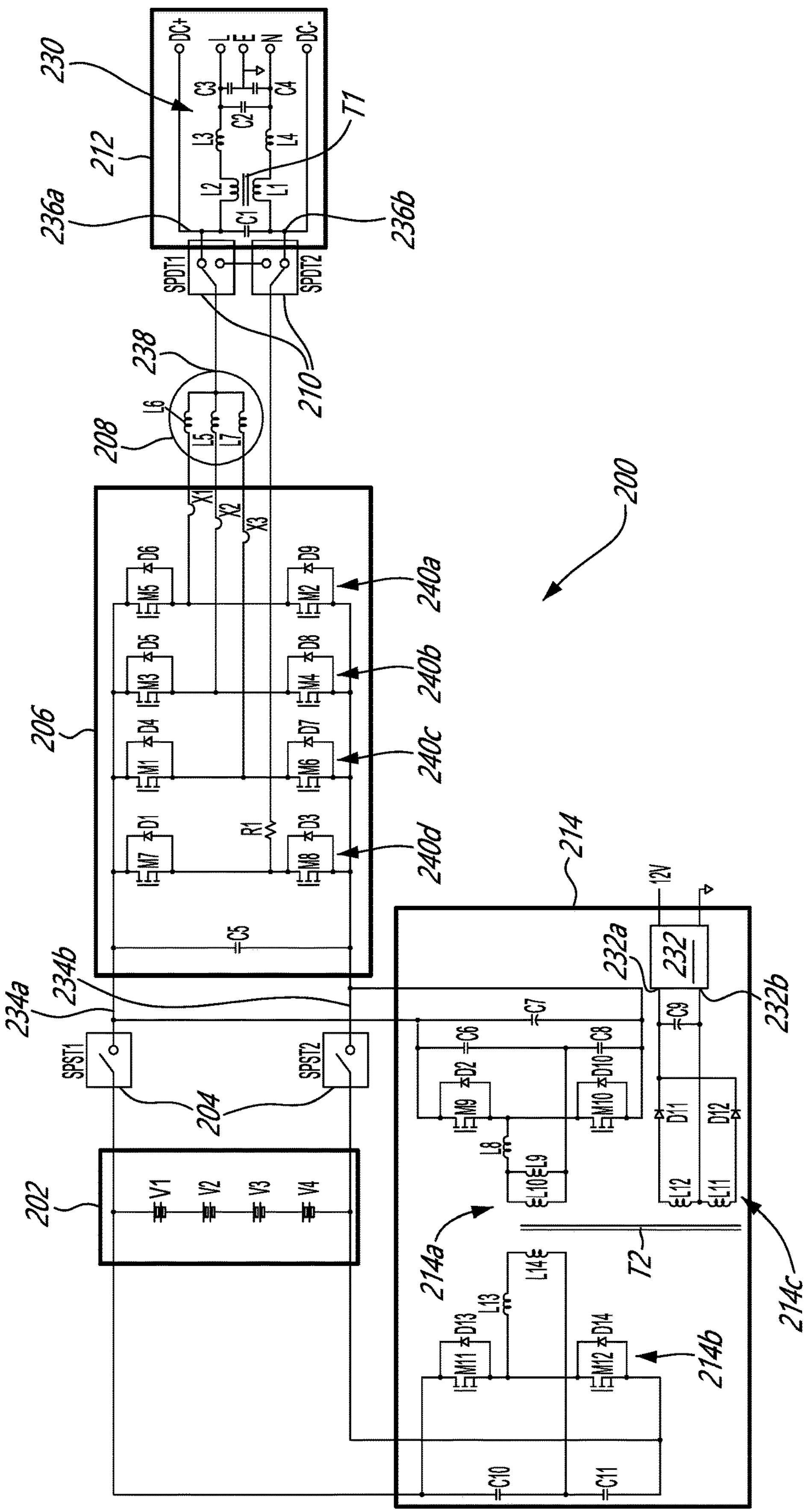

200
202
Traction Battery
204
Contactors
206
Power Electronics Module
208
Electric Motor
210
Contactors
212
Charging Port
214
DC-to-DC Converter
214a
214b
214c
216
Low-voltage System(s)
220
Controller(s)
218
Ancillary Battery

FIG - 2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232a
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236b
238
240a
240b
240c
240d
T1
T2
DC+
L
E
N
DC-
SPDT1
SPDT2
SPST1
SPST2
12V
X1
X2
X3
V1
V2
V3
V4
R1
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
L1
L2
L3
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M12
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D14

FIG-3

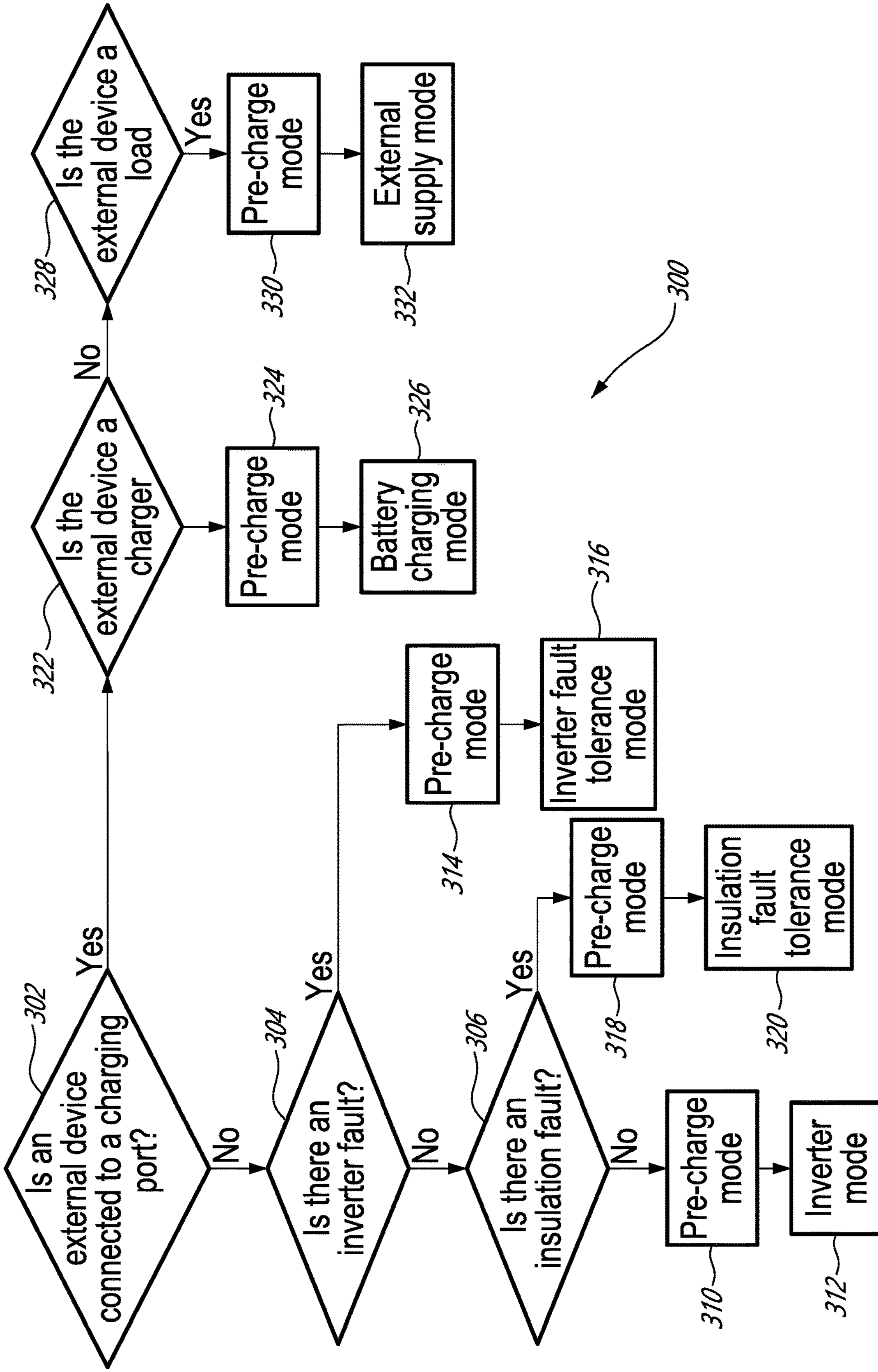
Is an external device connected to a charging port?
302
Yes
No
Is there an inverter fault?
304
Is there an insulation fault?
306
Pre-charge mode
310
Inverter mode
312
Pre-charge mode
314
Inverter fault tolerance mode
316
Pre-charge mode
318
Insulation fault tolerance mode
320
Is the external device a charger
322
Pre-charge mode
324
Battery charging mode
326
Is the external device a load
328
Pre-charge mode
330
External supply mode
332
300

FIG. 4

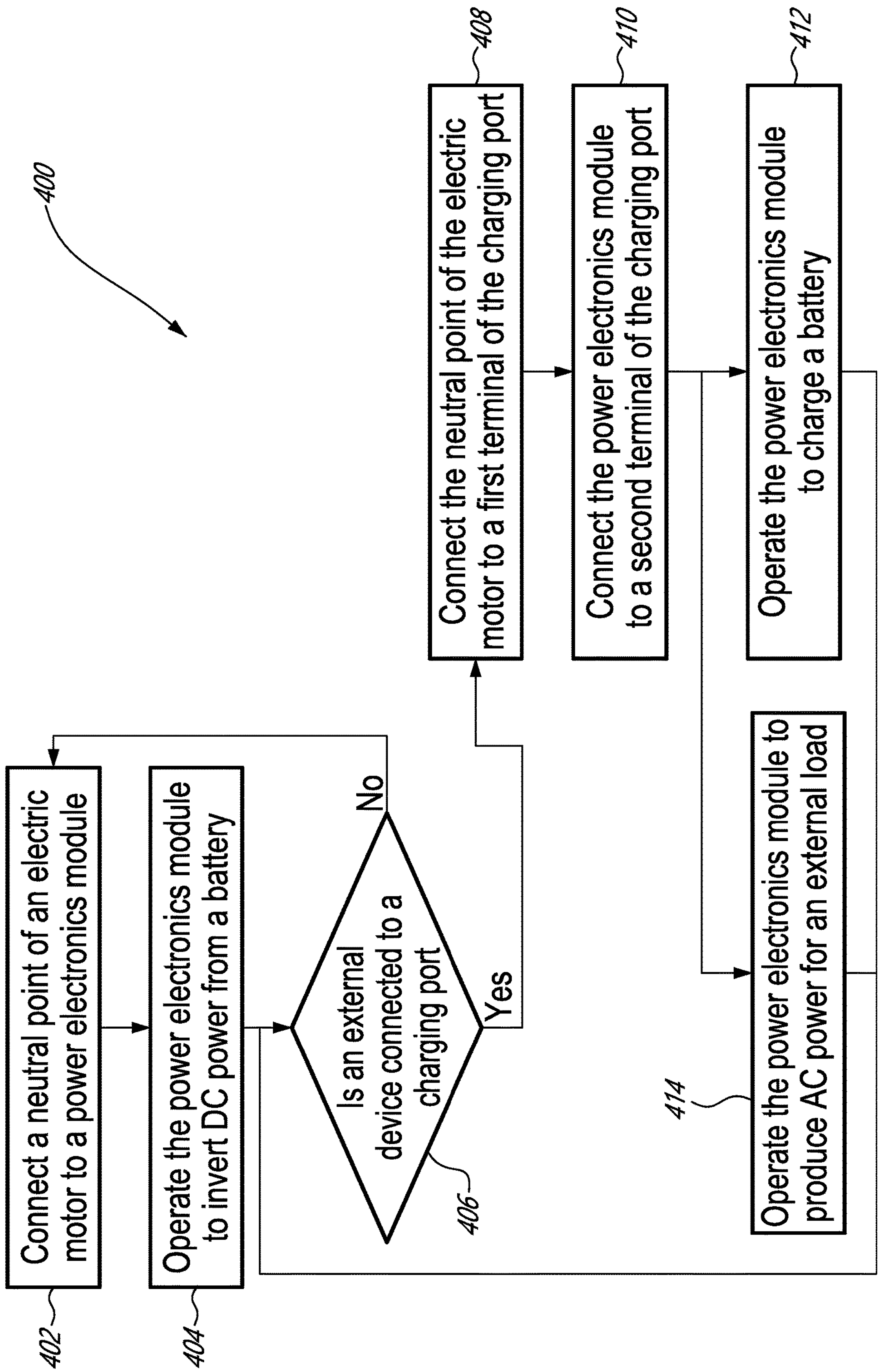
400
Connect a neutral point of an electric motor to a power electronics module
402
Operate the power electronics module to invert DC power from a battery
404
Is an external device connected to a charging port
406
No
Yes
Connect the neutral point of the electric motor to a first terminal of the charging port
408
Connect the power electronics module to a second terminal of the charging port
410
Operate the power electronics module to charge a battery
412
Operate the power electronics module to produce AC power for an external load
414

FIG. 5

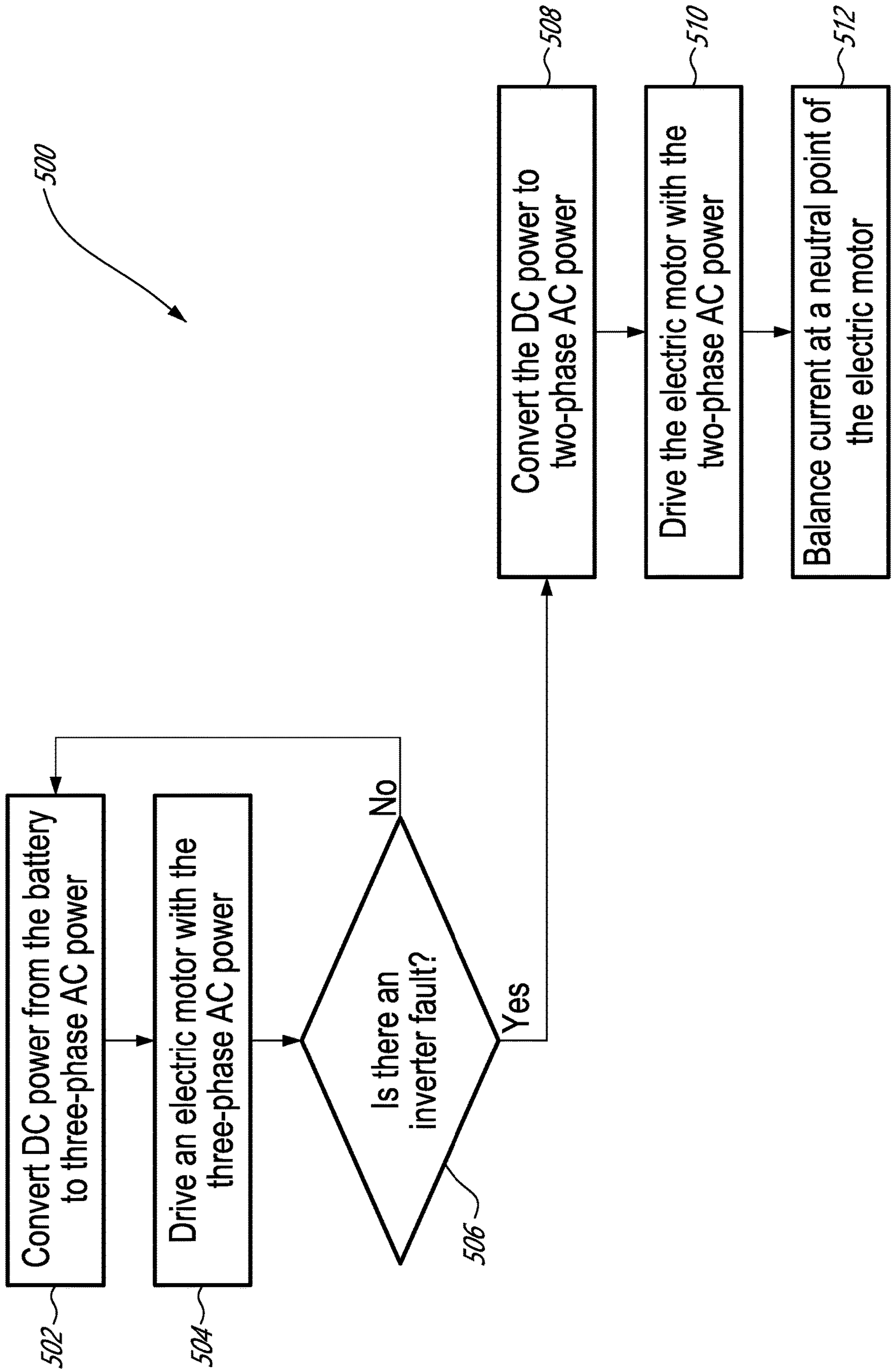
500
Convert DC power from the battery to three-phase AC power
502
Drive an electric motor with the three-phase AC power
504
Is there an inverter fault?
506
No
Yes
Convert the DC power to two-phase AC power
508
Drive the electric motor with the two-phase AC power
510
Balance current at a neutral point of the electric motor
512

FIG. 6

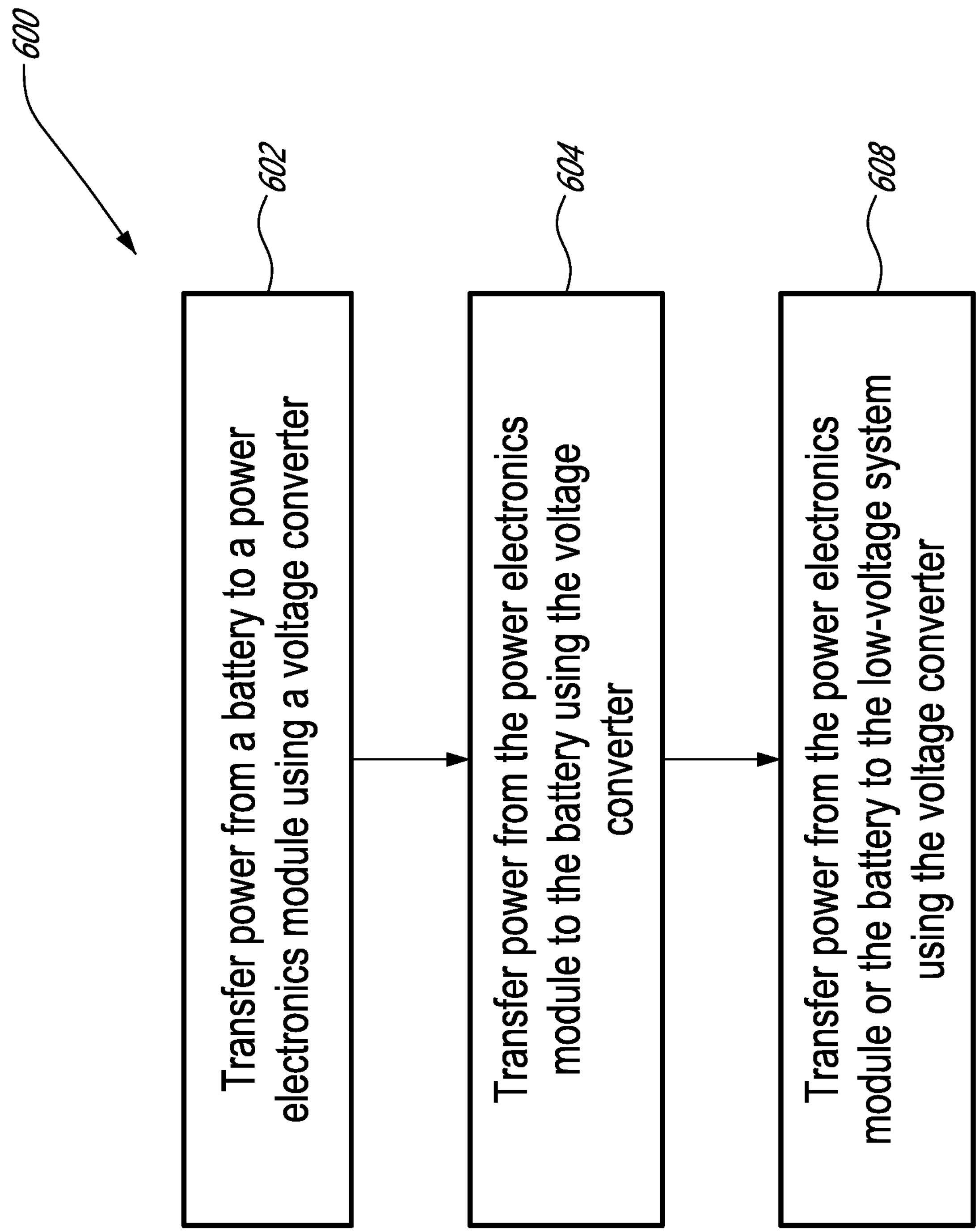
600
602
Transfer power from a battery to a power electronics module using a voltage converter
604
Transfer power from the power electronics module to the battery using the voltage converter
608
Transfer power from the power electronics module or the battery to the low-voltage system using the voltage converter

FIG. 7

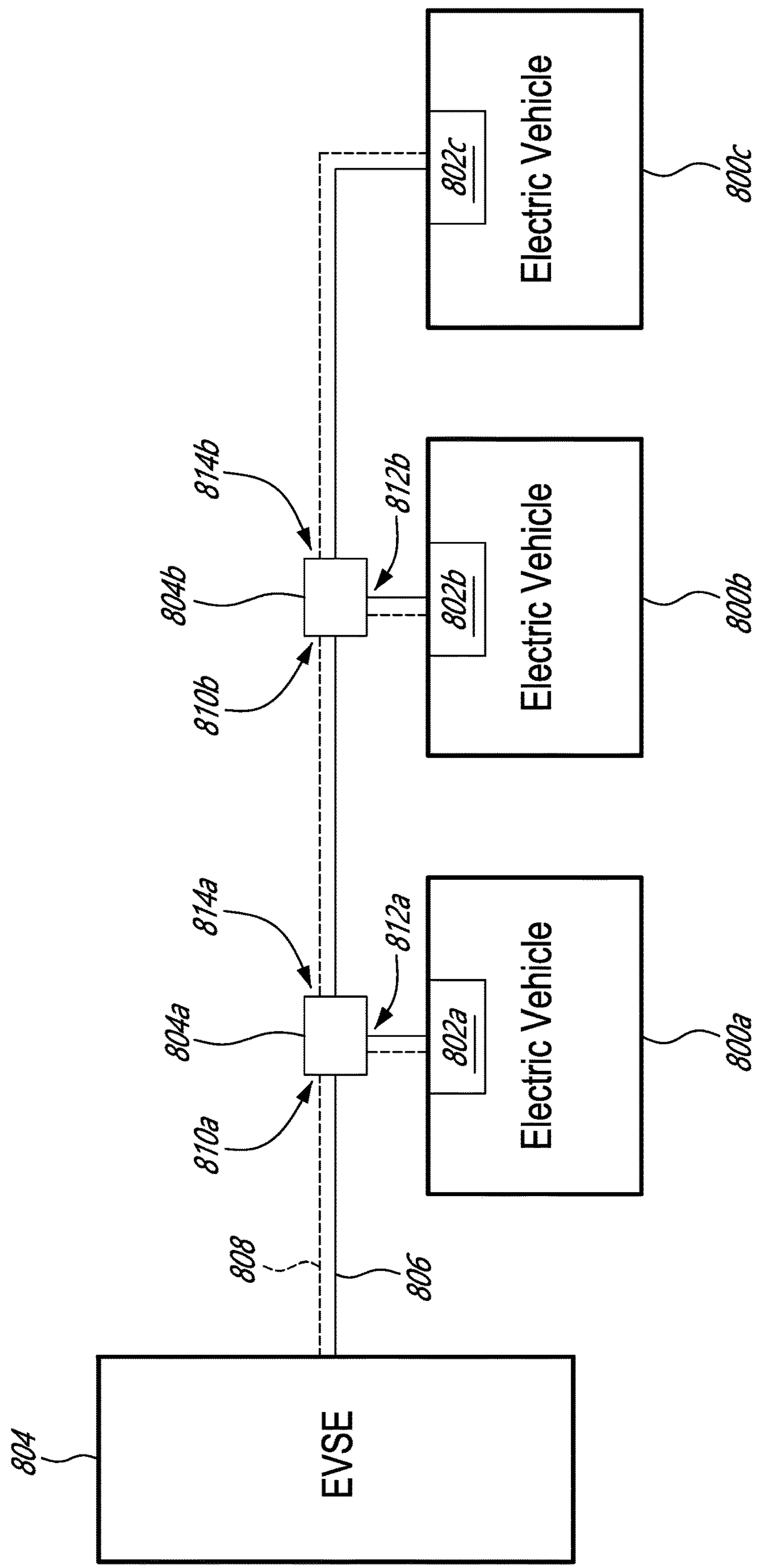
EVSE
804
808
806
Electric Vehicle
Electric Vehicle
Electric Vehicle
802a
802b
802c
800a
800b
800c
804a
804b
810a
810b
812a
812b
814a
814b

FIG. 8

ELECTRONIC SYSTEMS FOR ELECTRIC VEHICLES AND RELATED METHODS

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims priority from U.S. Provisional Patent Application No. 63/431,817, filed Dec. 12, 2022, which is incorporated by reference in its entirety herein.

TECHNICAL FIELD

[0002] The disclosure relates generally to electric vehicles, and more particularly to electronic systems for electric vehicles.

BACKGROUND

[0003] Electric vehicles typically include one or more electronic systems to perform a wide variety of tasks, including charging a battery of the electric vehicle, controlling power delivery to an electric motor, and powering various vehicle sub-systems, for example. Some electronic systems include a large number of components to enable these tasks, which may increase the complexity and cost of the systems. Further, some electronic systems do not have sufficient fault tolerance that can maintain essential vehicle operations in the event of component failures. Improvement is desired.

SUMMARY

[0004] Aspects of the present disclosure provide electronic systems for electric vehicles that provide additional functionality, use fewer components, and/or improve fault tolerance. Related methods are also provided.

[0005] In one aspect, the disclosure describes a system for an electric vehicle including a battery; a power electronics module to connect to the battery; an electric motor comprising a plurality of phase windings and a neutral point, each of the plurality of phase windings connected between the power electronics module and the neutral point; a port to connect to an external device, the port comprising a first terminal and a second terminal; and at least one electrical switch to selectively connect the first terminal of the port to the neutral point of the electric motor and to selectively connect the second terminal of the port to the power electronics module.

[0006] In some embodiments, the at least one electrical switch is to connect the first terminal of the port to the neutral point of the electric motor and to connect the second terminal of the port to the power electronics module when the port is connected to the external device.

[0007] In some embodiments, the external device comprises a charger providing alternating current (AC) power, and the electric motor and the power electronics module are to rectify and boost the AC power to charge the battery.

[0008] In some embodiments, the external device comprises a charger providing direct current (DC) power to charge the battery.

[0009] In some embodiments, the external device comprises an external load, and the port is to transfer power from the battery to the external load.

[0010] In some embodiments, the power electronics module is to invert direct current (DC) power from the battery to produce alternating current (AC) power for the external load.

[0011] In some embodiments, direct current (DC) power from the battery is provided to the external load.

[0012] In some embodiments, the at least one electrical switch is to disconnect the first terminal of the port from the neutral point of the electric motor and to disconnect the second terminal of the port from the power electronics module when the port is disconnected from the external device.

[0013] In some embodiments, the at least one electrical switch is to connect the neutral point of the electric motor to the power electronics module when the port is disconnected from the external device.

[0014] In some embodiments, when the port is disconnected from the external device, the power electronics module is to invert direct current (DC) power from the battery to produce alternating current (AC) power to drive the electric motor.

[0015] In some embodiments, the at least one electrical switch is at least one first electrical switch, and the system comprises at least one second electrical switch to selectively connect the battery to the power electronics module to provide the DC power to the power electronics module.

[0016] In some embodiments, the at least one electrical switch comprises a first electrical switch to selectively connect the first terminal of the port to the neutral point and a second electrical switch to selectively connect the second terminal the port to the power electronics module.

[0017] In some embodiments, the plurality of phase windings comprises three phase windings, the power electronics module comprises three sets of electrical switches connected to three phase windings, respectively, and the power electronics module further comprises a fourth set of electric switches to connect to the second terminal the port.

[0018] In some embodiments, the system comprises a first bus and a second bus connecting the battery to the power electronics module, the fourth set of electrical switches comprises a first electrical switch and a second electrical switch connected in series between the first bus and the second bus, and the at least one switch is to connect the second terminal of the port between the first electrical switch and the second electrical switch of the fourth set of electrical switches.

[0019] In some embodiments, where the system comprises a voltage converter to connect the power electronics module to the battery.

[0020] In some embodiments, the voltage converter is a bi-directional direct current-to-direct current (DC-to-DC) converter.

[0021] In some embodiments, the external device comprises a charger providing an alternating current (AC) power, the electric motor and power electronics module are to rectify and boost the AC power to produce DC power, and the voltage converter is to alter a voltage of the DC power to charge the battery.

[0022] In some embodiments, the system comprises a low-voltage system, and the bi-directional DC-to-DC converter to reduce the voltage of the DC power to power the low-voltage system.

[0023] In some embodiments, the power electronics module comprises a capacitor, and the bi-directional DC-to-DC converter is to pre-charge the capacitor using the battery prior to charging the battery.

[0024] In some embodiments, the bi-directional DC-to-DC converter galvanically isolates the battery and the port.

[0025] In some embodiments, when the external device comprises an external load and is connected to the charge port, the bi-directional DC-to-DC converter is to receive direct current (DC) power from the battery and alter a voltage of the DC power for the external load.

[0026] In some embodiments, the system comprises low-voltage system, and the bi-directional DC-to-DC converter to reduce the voltage of the DC power to power the low-voltage system.

[0027] In some embodiments, the port comprises an electromagnetic interference filter.

[0028] In some embodiments, the port includes connections for alternating current (AC) supply power and direct current (DC) supply power.

[0029] In some embodiments, the system comprises a current sensor connected between the second terminal of the port and the power electronics module.

[0030] Embodiments may include combinations of the above features.

[0031] In another aspect, the disclosure describes a system for an electric vehicle, the system including an electric motor comprising three phase windings connected to a neutral point; a power electronics module comprising three sets of electrical switches connected to the three phase windings, respectively, and a fourth set of electrical switches to connect to the neutral point; a battery to connect to the power electronics module; and a port to connect to the neutral point and to the fourth set of switches.

[0032] In some embodiments, the three sets of electrical switches are to convert direct current (DC) power from the battery to alternating current (AC) power to drive the electric motor.

[0033] In some embodiments, when the three sets of electrical switches are converting DC power from the battery to AC power to drive the electric motor, the port is disconnected from the neutral point and disconnected from the fourth set of electrical switches.

[0034] In some embodiments, when the three sets of electrical switches are converting DC power from the battery to AC power to drive the electric motor, the fourth set of electrical switches is inactive.

[0035] In some embodiments, when the three sets of electrical switches comprise a non-functional set of switches, the remaining two sets of electrical switches are to convert DC power from the battery to AC power to drive the electric motor.

[0036] In some embodiments, when the remaining two sets of electrical switches are converting DC power from the battery to AC power to drive the electric motor, the fourth set of switches is connected to the neutral point to provide a current path from the neutral point to the battery.

[0037] In some embodiments, the system comprises a first bus and a second bus connecting the battery to the power electronics module, the fourth set of electrical switches comprises a first electrical switch and a second electrical switch connected in series between the first bus and the second bus, and when the remaining two sets of electrical switches are converting DC power from the battery to AC power to drive the electric motor, the neutral point is connected between the first electrical switch and the second electrical switch to provide a current path from the neutral point to first bus and the second bus.

[0038] In some embodiments, the system comprises at least one electrical switch to selectively connect the port between the neutral point of the electric motor and the fourth set of electrical switches.

[0039] In some embodiments, the port comprises a first terminal to connect to the neutral point of the electric motor and a second terminal to connect to the fourth set of electrical switches.

[0040] In some embodiments, the at least one electrical switch is to disconnect the first terminal of the port from the neutral point of the electric motor and to disconnect the second terminal of the port from the fourth set of electrical switches when the port is disconnected from an external device.

[0041] In some embodiments, the at least one electrical switch is to connect the neutral point of the electric motor to the fourth set of electrical switches when the port is disconnected from the external device.

[0042] In some embodiments, the at least one electrical switch is at least one first electrical switch, the system comprises at least one second electrical switch to selectively connect the battery to the power electronics module.

[0043] In some embodiments, the at least one electrical switch is to connect the first terminal of the port to the neutral point of the electric motor and to connect the second terminal of the port to the fourth set of electrical switches when the port is connected to the external device.

[0044] In some embodiments, the external device comprises a charger providing alternating current (AC) power, and the electric motor and the power electronics module are to rectify the AC power to charge the battery.

[0045] In some embodiments, the external device comprises a charger providing direct current (DC) power, and the electric motor and the power electronics module are to boost a voltage of the DC power to charge the battery.

[0046] In some embodiments, the external device comprises an external load, and the port is to transfer power from the battery to the external load.

[0047] In some embodiments, the electric motor and the power electronics module are to convert direct current (DC) power from the battery to alternating current (AC) power for the external load.

[0048] In some embodiments, direct current (DC) power from the battery is provided to the external load.

[0049] In some embodiments, the at least one electrical switch comprises a first electrical switch to selectively connect the first terminal of the port to the neutral point and a second electrical switch to selectively connect the second terminal the port to the fourth set of electrical switches.

[0050] In some embodiments, the system comprises a first bus and a second bus connecting the battery to the power electronics module, the fourth set of electrical switches comprises a first electrical switch and a second electrical switch connected in series between the first bus and the second bus, and the at least one switch is to connect the second terminal of the port between the first electrical switch and the second electrical switch of the fourth set of electrical switches.

[0051] In some embodiments, the system comprises a voltage converter to connect the power electronics module to the battery.

[0052] In some embodiments, the voltage converter is a bi-directional direct current-to-direct current (DC-to-DC) converter.

[0053] In some embodiments, the external device comprises a charger providing an alternating current (AC) power, the electric motor and power electronic module to rectify and boost the AC power to provide DC power, and the voltage converter to alter a voltage of the DC power to charge the battery.

[0054] In some embodiments, the system comprises a low-voltage system, and the voltage converter is to reduce the voltage of the DC power to power the low-voltage system.

[0055] In some embodiments, the power electronics module comprises a capacitor, and the voltage converter is to pre-charge the capacitor using the battery prior to charging the battery.

[0056] In some embodiments, the voltage converter galvanically isolates the battery and the port.

[0057] In some embodiments, when an external device comprising an external load is connected to the charge port, the voltage converter is to receive direct current (DC) power from the battery and alter a voltage of the DC power for the external load.

[0058] In some embodiments, the system comprises a low-voltage system, and the voltage converter is to reduce the voltage of the DC power to power the low-voltage system.

[0059] In some embodiments, the port comprises an electromagnetic interference filter.

[0060] In some embodiments, the port includes connections for alternating current (AC) supply power and direct current (DC) supply power.

[0061] In some embodiments, the system comprises a current sensor connected between the second terminal of the port and the power electronics module.

[0062] Embodiments may include combinations of the above features.

[0063] In a further aspect, the disclosure describes a system for an electric vehicle, the system comprising a battery having a first voltage; a low-voltage system operating at a second voltage lower than the first voltage; a power electronics module; an electric motor connected to the power electronics module; and a voltage converter. The voltage converter comprises a primary side connected to the power electronics module, a secondary side connected to the battery, and a tertiary side connected to the low-voltage system.

[0064] In some embodiments, the voltage converter is a bi-directional direct current-to-direct current (DC-to-DC) converter.

[0065] In some embodiments, the bi-directional DC-to-DC converter comprises a transformer.

[0066] In some embodiments, the primary side comprises at least one primary side switch and the secondary side comprises at least one secondary side switch.

[0067] In some embodiments, the tertiary side comprises a rectifier and regulator.

[0068] In some embodiments, the system comprises a port connected to an external device, the port to connect to the electric motor and to the power electronics module.

[0069] In some embodiments, the external device comprises a charger providing a first alternative current (AC) power, the electric motor and power electronics module rectify and boost the first AC power to produce a first DC power, the at least one primary side switch is to invert the first DC power and provide a second AC power to the transformer, and the at least one secondary side switch is to rectify the second AC power from the transformer and provide a second DC power to charge the battery.

[0070] In some embodiments, a duty cycle of the at least one first side switch and a duty cycle of the at least one secondary side switch is adjusted based on the first voltage of the battery to produce the second DC power to charge the battery.

[0071] In some embodiments, the rectifier and regulator of the tertiary side are to rectify the second AC power to provide a third DC power having the second voltage to power the low-voltage system.

[0072] In some embodiments, the transformer galvanically isolates the battery and the port.

[0073] In some embodiments, the at least one secondary switch is to invert a first DC power from the battery to product a first alternative current (AC) power to the transformer, and the at least one primary side switch is to rectify the first AC power and provide a second DC power to the power electronics module.

[0074] In some embodiments, the power electronics module comprises a capacitor, and the second DC power is to charge the capacitor.

[0075] In some embodiments, the system comprises at least one switch to connect the battery to the power electronics module, and the second DC power is to pre-charge the capacitor prior to closing the at least one switch.

[0076] In some embodiments, the second DC power is to pre-charge the capacitor prior to charging the battery.

[0077] In some embodiments, the system comprises at least one switch to connect the battery to the power electronics module, and the second DC power is to power the power electronics module and drive the electric motor when the at least one switch is non-functioning.

[0078] In some embodiments, the system comprises a port connected to an external load, the port to connect to the electric motor and to the power electronics module.

[0079] In some embodiments, the power electronics module and electric motor are to invert the second DC power to produce a second AC power, and the port is to provide the second AC power to the external load.

[0080] In some embodiments, the rectifier and regulator of the tertiary side is to rectify the first AC power to provide a third DC power having the second voltage to power the low-voltage system.

[0081] In some embodiments, the system comprises at least one switch to connect the battery to the power electronics module, and when the at least one switch is closed, the battery provides a first DC power to the power electronics module and to the at least one primary side switch, the at least one secondary switch is to invert the first DC power from the battery to product an alternative current (AC) power to the transformer; and the rectifier and regulator of the tertiary side are to rectify the AC power to provide a second DC power having the second voltage to power the low-voltage system.

[0082] Embodiments may include combinations of the above features.

[0083] In a further aspect, the disclosure describes a method for an electric vehicle comprising an electric motor, a power electronics module, and a port. The method includes connecting a neutral point of the electric motor to the power electronics module to drive the electric motor and, responsive to an external device being connected to the port, connecting the neutral point of the electric motor to a first terminal of the port and connecting the power electronics module to a second terminal of the port.

[0084] In some embodiments, the external device comprises a charger providing alternating current (AC) power, the method comprising operating the power electronics module to rectify and boost the AC power to produce direct current (DC) power to charge a battery of the electric vehicle.

[0085] In some embodiments, method comprises operating a voltage converter of the electric vehicle to alter a voltage of the DC power to charge the battery.

[0086] In some embodiments, the method comprises operating the voltage converter to reduce the voltage of the DC power to power a low-voltage system of the electric vehicle.

[0087] In some embodiments, the power electronics module comprises a capacitor, the method comprising operating the voltage converter to pre-charge the capacitor using the battery prior to charging the battery.

[0088] In some embodiments, operating the voltage converter to alter the voltage of the DC power to charge the battery comprises galvanically isolating the battery from the port.

[0089] In some embodiments, the voltage converter is a bi-directional DC-to-DC converter.

[0090] In some embodiments, the method comprises filtering electromagnetic interference using a filter integrated in the port.

[0091] In some embodiments, the power electronics module comprises three sets of electrical switches connected to the motor and a fourth set of electrical switches, and connecting the power electronics module to the second terminal of the port comprises connecting the fourth set of switches to the second terminal of the port.

[0092] In some embodiments, the fourth set of switches comprises a first switch and a second switch connected in series, and connecting the fourth set of switches to the second terminal of the port comprises connecting the second terminal between the first switch and the second switch.

[0093] In some embodiments, operating the power electronics module to rectify and boost the AC power to produce the DC power comprises operating the three sets of electrical switches as at least part of a first leg of a rectifier and operating the fourth set of electrical switches as at least part of a second leg of the rectifier.

[0094] In some embodiments, the external device comprises an external load, the method comprises operating the power electronics module to invert direct current (DC) power from a battery of the electric vehicle to produce alternating current (AC) power for the external load.

[0095] In some embodiments, method comprises operating a voltage converter of the electric vehicle to alter a voltage of the DC power from the battery.

[0096] In some embodiments, the voltage converter is a bi-directional DC-to-DC converter.

[0097] In some embodiments, the power electronics module comprises three sets of electrical switches connected to the motor and a fourth set of electrical switches, and connecting the power electronics module to the second terminal of the port comprises connecting the fourth set of switches to the second terminal of the port.

[0098] In some embodiments, the fourth set of switches comprises a first switch and a second switch connected in series, and connecting the fourth set of switches to the second terminal of the port comprises connecting the second terminal between the first switch and the second switch.

[0099] In some embodiments, operating the power electronics module to invert the DC power from the battery to produce AC power comprises operating the three sets of electrical switches as at least part of a first leg of an inverter and operating the fourth set of electrical switches as at least part of a second leg of the inverter.

[0100] In some embodiments, the method comprises, responsive to the external device being disconnected from the port, reconnecting the neutral point of the electric motor to the power electronics module.

[0101] In some embodiments, the method comprises operating the power electronics module to invert direct current (DC) power from a battery of the electric vehicle to produce alternating current (AC) power to drive the electric motor when the external device is disconnected from the port.

[0102] Embodiments may include combinations of the above features.

[0103] In a further aspect, the disclosure describes a method for an electric vehicle comprising an electric motor, a power electronics module, and a battery. The method includes converting direct current (DC) power from the battery to three-phase alternating current (AC) power using three sets of electrical switches in the power electronics module, driving the electric motor with the three-phase AC power and, responsive to one of the three sets of electrical switches being non-functional, converting the DC power from the battery to two-phase AC power using the remaining two sets of electrical switches, driving the electric motor with the two-phase AC power, and balancing current at a neutral point of the electric motor using a fourth set of electrical switches in the power electronics module.

[0104] In some embodiments, the fourth set of electrical switches are inactive when converting the DC power from the battery to the three-phase AC power.

[0105] In some embodiments, balancing the current at the neutral point of the electric motor comprises operating the fourth set of electrical switches to provide a current path from the neutral point to the battery.

[0106] In some embodiments, the electric vehicle comprises a first bus and a second bus connecting the battery to the power electronics module, the fourth set of electrical switches comprises a first electrical switch and a second electrical switch connected in series between the first bus and the second bus, and operating the fourth set of switches to provide a current path from the neutral point to the battery comprises operating the first electrical switch and the second electrical switch to provide a current path from the neutral point to first bus and the second bus.

[0107] Embodiments may include combinations of the above features.

[0108] In a further aspect, the disclosure describes a method for an electric vehicle comprising a voltage converter, a power electronics module, a battery, and a low-voltage system. The method includes transferring power from the battery to the power electronics module using the voltage converter, transferring power from the power electronics module to the battery using the voltage converter, and transferring power from the power electronics module or the battery to the low-voltage system using the voltage converter.

[0109] In some embodiments, the voltage converter comprises a bi-directional direct current-to-direct current (DC-to-DC) converter having a primary side connected to the power electronics module, a secondary side connected to the battery, a tertiary side connected to the low-voltage system, and a transformer connecting the primary side, the secondary side and the tertiary side.

[0110] In some embodiments, transferring power from the battery to the power electronics module using the voltage converter comprises inverting, using the secondary side, first DC power from the battery to produce AC power at the transformer, and rectifying, using the primary side, the AC power from the transformer to provide second DC power for the power electronics module.

[0111] In some embodiments, the electric vehicle is connected to an external load, and transferring power from the battery to the power electronics module using the voltage converter comprises adjusting a duty cycle of at least one primary side switch of the primary side and a duty cycle of at least one secondary side switch at the secondary side based on a voltage requirement of the external load.

[0112] In some embodiments, transferring power from the power electronics module to the battery using the voltage converter comprises inverting, using the primary side, first DC power from the power electronics module to produce AC power at the transformer, and rectifying, using the secondary side, the AC power from the transformer to provide second DC power to charge the battery.

[0113] In some embodiments, transferring power from the power electronics module to the battery using the voltage converter comprises galvanically isolating the battery from the power electronics module using the transformer.

[0114] In some embodiments, transferring power from the power electronics module to the battery using the voltage converter comprises adjusting a duty cycle of at least one primary side switch of the primary side and a duty cycle of at least one secondary side switch at the secondary side based on a voltage of the battery to produce the second DC power to charge the battery.

[0115] In some embodiments, transferring power from the power electronics module or the battery to low-voltage system using the voltage converter comprises inverting, using the primary side, first DC power from the power electronics module to produce AC power at the transformer, and rectifying, using the tertiary side, the AC power from the transformer to provide second DC power to power the low-voltage systems.

[0116] In some embodiments, transferring power from the power electronics module or the battery to low-voltage system using the voltage converter comprises inverting, using the secondary side, first DC power from the battery to produce AC power at the transformer, and rectifying, using the tertiary side, the AC power from the transformer to provide second DC power to power the low-voltage systems.

[0117] In some embodiments, rectifying, using the tertiary side, the AC power from the transformer to provide the second DC power comprises regulating a voltage of the second DC power using a voltage regulator.

[0118] In some embodiments, transferring power from the battery to the power electronics module using the voltage converter comprises pre-charging a capacitor of the power electronics module.

[0119] Embodiments may include combinations of the above features.

[0120] Further details of these and other aspects of the subject matter of this application will be apparent from the detailed description included below and the drawings.

DESCRIPTION OF THE DRAWINGS

[0121] Reference is now made to the accompanying drawings, in which:

[0122] FIG. **1**A is a side plan view of an exemplary snowmobile according to some embodiments of the present disclosure;

[0123] FIG. **1**B is a side plan view of the snowmobile of FIG. **1** showing internal components thereof;

[0124] FIG. **1**C is a perspective view of part of the snowmobile of FIG. **1** including an electric motor;

[0125] FIG. **2** is a block diagram illustrating a system **200** according to some embodiments of the present disclosure;

[0126] FIG. **3** is a circuit diagram for the system of FIG. **2**, according to an embodiment;

[0127] FIG. **4** is a flow diagram illustrating a method of selecting an operating mode from multiple possible operating modes of the system of FIG. **2**, according to an embodiment;

[0128] FIGS. **5** to **7** are flow diagrams illustrating methods according to embodiments of the present disclosure; and

[0129] FIG. **8** is a block diagram illustrating multiple electric vehicles connected to and being charged by a single electric vehicle supply equipment according to an embodiment.

DETAILED DESCRIPTION

[0130] The following disclosure relates to electronics systems for use in electric vehicles, including on-road and off-road vehicles. Non-limiting examples of electric vehicles suitable for the systems and methods described herein include cars, trucks, snowmobiles, motorcycles, watercraft such as boats and personal watercraft (PWC), all-terrain vehicles (ATVs), and utility task vehicles (UTVs) (e.g., side-by-sides). An example of such an electric vehicle is provided below.

[0131] FIG. **1**A illustrates a side plan view of a snowmobile **100**, according to an embodiment, and FIG. **1**B illustrates another side plan view of the snowmobile **100** with several body panels and other components removed so that the interior of the snowmobile **100** may be viewed. The snowmobile **100** includes a frame **102**, which may also be referred to as a "chassis" or "body", that provides a load bearing framework for the snowmobile **100**. In the illustrated embodiment, the frame **102** includes a longitudinal tunnel **104**, a mid-bay **106** (or "bulkhead") coupled forward of the tunnel **104**, and a front sub-frame **108** (or "front brace") coupled forward of the mid-bay **106**. In some implementations, the mid-bay **106** may form part of the front sub-frame **108**.

[0132] The snowmobile **100** also includes a rear suspension assembly **110** and a front suspension assembly **112** to provide shock absorption and improve ride quality. The rear suspension assembly **110** may be coupled to the underside of the tunnel **104** to facilitate the transfer of loads between the rear suspension assembly **110** and the tunnel **104**. The rear suspension assembly **110** supports a drive track **114** having the form of an endless belt for engaging the ground (e.g., snow) and propelling the snowmobile **100**. The rear suspension assembly may include, inter alia, one or more rails and/or idler wheels for engaging with the drive track **114**, and one or more control arms and damping elements (e.g., elastic elements such as coil and/or torsion springs forming a shock absorber) connecting the rails to the tunnel **104**. The front suspension assembly **112** includes two suspension legs **116** coupled to the front sub-frame **108** and to respective ground engaging front skis **118** (only one suspension leg **116** and ski **118** are visible in FIGS. **1**A and **1**B). Each of the suspension legs **116** may include two A-frame arms connected to the front sub-frame **108**, a damping element (e.g., an elastic element) connected to the front sub-frame **108**, and a spindle connecting the A-frame arms and the damping element to a respective one of the skis **118**. The suspension legs **116** transfer loads between the skis **118** and the front sub-frame **108**. In the illustrated embodiment, the frame **102** also includes an over structure **120** (shown in FIG. **1**B), that may include multiple members (e.g., tubular members) interconnecting the tunnel **104**, the mid-bay **106** and/or the front sub-frame **108** to provide additional rigidity to the frame **102**. However, as discussed elsewhere herein, the over structure **120** may be omitted in some embodiments.

[0133] The snowmobile **100** may move along a forward direction of travel **122** and a rearward direction of travel **124** (shown in FIG. **1**A). The forward direction of travel **122** is the direction along which the snowmobile **100** travels in most instances when displacing. The rearward direction of travel **124** is the direction along which the snowmobile **100** displaces only occasionally, such as when it is reversing. The snowmobile **100** includes a front end **126** and a rear end **128** defined with respect to the forward direction of travel **122** and the rearward direction of travel **124**. For example, the front end **126** is positioned ahead of the rear end **128** relative to the forward direction of travel **122**. The snowmobile **100** defines a longitudinal center axis **130** that extends between the front end **126** and the rear end **128**. Two opposing lateral sides of the snowmobile **100** are defined parallel to the center axis **130**. The positional descriptors "front", "rear" and terms related thereto are used in the present disclosure to describe the relative position of components of the snowmobile **100**. For example, if a first component of the snowmobile **100** is described herein as being in front of, or forward of, a second component, then the first component is closer to the front end **126** than the second component. Similarly, if a first component of the snowmobile **100** is described herein as being behind, or rearward of, a second component, then the first component is closer to the rear end **128** than the second component. The snowmobile **100** also includes a three-axes frame of reference that is displaceable with the snowmobile **100**, where the Z-axis is parallel to the vertical direction, the X-axis is parallel to the center axis **130**, and the Y-axis is parallel to the lateral direction.

[0134] The snowmobile **100** is configured to carry one or more riders, including a driver (sometimes referred to as an "operator") and optionally one or more passengers. In the illustrated example, the snowmobile **100** includes a straddle seat **140** to support the riders. Optionally, the straddle seat **140** includes a backrest **142**. The operator of the snowmobile **100** may steer the snowmobile **100** using a steering mechanism **144** (e.g., handlebars), which are operatively connected to the skis **118** via a steering shaft **146** to control the direction of the skis **118**. The tunnel **104** may also include or be coupled to footrests **148** (also referred to as "running boards"), namely left and right footrests each sized for receiving a foot of one or more riders sitting on the straddle seat **140**.

[0135] Referring to FIG. **1**B, the snowmobile **100** is electrically propelled by an electric powertrain **150**. The powertrain **150** includes an electric battery **152** (also referred to as a "battery pack") and an electric motor **170**. The battery **152** is electrically connected to the motor **170** to provide electric power to the motor **170**. The motor **170**, in turn, is drivingly coupled to the drive track **114** to propel the snowmobile **100** across the ground. In other embodiments, the snowmobile **100** may also or instead be propelled by a powertrain including an internal combustion engine. For example, the motor **170** may also or instead be an internal combustion engine.

[0136] The battery **152** may include a battery enclosure **158** that houses one or more battery modules **160**. The battery enclosure **158** may support the battery modules **160** and protect the battery modules **160** from external impacts, water and/or other hazards or debris. Each battery module **160** may contain one or more battery cells, such as pouch cells, cylindrical cells and/or prismatic cells, for example. In some implementations, the battery cells are rechargeable lithium-ion battery cells. The battery **152** may also include other components to help facilitate and/or improve the operation of the battery **152**, including temperature sensors to monitor the temperature of the battery cells, voltage sensors to measure the voltage of one or more battery cells, current sensors to implement column counting to infer the state of charge (SOC) of the battery **42**, and/or thermal channels that circulate a thermal fluid to control the temperature of the battery cells. In some implementations, the battery **152** may output electric power at a voltage of between 300 and 800 volts, for example. The snowmobile **100** may also include a charger **162** to convert AC to DC current from an external power source to charge the battery **152**. The charger **162** may include, or be connected to, a charging port positioned forward of the straddle seat **140** to connect to a charging cable from an external power source. In some implementations, the charging port is covered by one or more protective flaps (e.g., made of plastic and/or rubber) to protect the charging port from water, snow and other debris. In some embodiments described elsewhere herein, a charger may be implemented by the electric motor **170** rather than being a separate component thereto.

[0137] In some implementations, the battery **152** may be generally divided into a tunnel battery portion **154** and a mid-bay battery portion **156**. The tunnel battery portion **154** may be positioned above and coupled to the tunnel **104**. As illustrated, the straddle seat **140** is positioned above the tunnel battery portion **154** and, optionally, the straddle seat **140** may be supported by the battery enclosure **158** and/or internal structures within the battery **152**. The mid-bay battery portion **156** extends into the mid-bay **106** and may be coupled to the mid-bay **106** and/or to the front sub-frame **108**. The tunnel battery portion **154** and the mid-bay battery portion **156** may share a single battery enclosure **158**, or alternatively separate battery enclosures. In the illustrated example, the tunnel battery portion **154** and the mid-bay battery portion **156** each include multiple battery modules **160** that are arranged in a row and/or stacked within the battery enclosure **158**.

[0138] It should be noted that other shapes, sizes and configurations of the battery **152** are contemplated. For example, the battery **152** may include multiple batteries that are interconnected via electrical cables. In some embodiments, the battery enclosure **158** may be a structural component of the snowmobile **100** and may form part of the frame **102**. For example, the battery enclosure **158** may be coupled to the front sub-frame **108** to transfer loads between the front sub-frame **108** and the tunnel **104**. The battery enclosure **158** may be formed from a fiber composite material (e.g., a carbon fiber composite) for additional rigidity. Optionally, in the case that the battery enclosure **158** is a structural component of the snowmobile **100**, the over structure **120** may be omitted.

[0139] FIG. **1**C is a perspective view of the mid-bay **106** of the snowmobile **100**. As illustrated, the motor **170** is disposed in a lower portion of the mid-bay **106**, below the mid-bay battery portion **156** and forward of a wall **164** defining a front end of the tunnel **104**. The motor **170** may be mounted to a transmission plate **166** that is supported between the tunnel **104** and the front sub-frame **108** to help support the motor **170** within the mid-bay **106**.

[0140] In the illustrated embodiment, the motor **170** is a permanent magnet synchronous motor having a rotor **172** and stator **173**. The motor **170** also includes power electronics module **174** (sometimes referred to as an inverter) to convert the direct current (DC) power from the battery **152** to alternating current (AC) power having a desired voltage, current and waveform to drive the motor **170**. In some implementations, the power electronics module **174** may include one or more capacitors to reduce the voltage variations between the high and low DC voltage leads, and one or more electric switches (e.g., insulated-gate bipolar transistors (IGBTs)) to generate the AC power. In some implementations, the motor **170** has a maximum output power of between 90 KW and 135 kW. In other implementations, the motor **170** has a maximum output power greater than 135 kW.

[0141] In some implementations, the motor **170** may include sensors configured to sense one or more parameters of the motor **170**. The sensors may be implemented in the rotor **172**, the stator **173** and/or the power electronics module **174**. The sensors may include a position sensor (e.g., an encoder) to measure a position and/or rotational speed of the rotor **172**, and/or a speed sensor (e.g., a revolution counter) to measure the rotational speed of the rotor **172**. Alternatively or additionally, the sensors may include a torque sensor to measure an output torque from the motor **170** and/or a current sensor (e.g., a Hall effect sensor) to measure an output current from the power electronics module **174**.

[0142] Other embodiments of the motor **170** are also contemplated. For example, the power electronics module **174** may be integrated into the housing or casing of motor **170**, as shown in FIG. **1**C. However, the power electronics module **174** may also, or instead, be provided externally to the housing or casing of motor **170**. In some embodiments, the motor **170** may be a type other than a permanent magnet synchronous motor. For example, the motor **170** may instead be a brushless direct current motor.

[0143] The motor **170** may convert the electric power output from the battery **152** into motive power that is transferred to the drive track **114** via a drive transmission **178**. The drive transmission **178** engages with a motor drive shaft **180** of the motor **170**. The motor drive shaft **180** may extend laterally through an opening in the transmission plate **166**. The drive transmission **178** includes a track drive shaft **182** that extends laterally across the tunnel **104**. The motor drive shaft **180** and the track drive shaft **182** may extend parallel to each other along transverse axes of the snowmobile **100** and may be spaced apart from each other along the longitudinal axis **130**. In the illustrated embodiment, the motor drive shaft **180** is operably coupled to the track drive shaft **182** via a drive belt **184**. Sprockets on the motor drive shaft **180** and the track drive shaft **182** may engage with lugs on the drive belt **184**. A drive belt idler pulley **186** may also be implemented to maintain tension on the drive belt **184**. In other embodiments, another form of linkage such as a drive chain, for example, may operatively connect the motor drive shaft **180** and the track drive shaft **182**.

[0144] In operation, torque from the motor **170** is transferred from the motor drive shaft **180** to the track drive shaft **182** via the drive belt **184**. The track drive shaft **182** includes one or more sprockets (not shown) that engage with lugs on the drive track **114**, thereby allowing the track drive shaft **182** to transfer motive power to the drive track **114**. It will be understood that the motor **170** may be operated in two directions (i.e., rotate clockwise or counter-clockwise), allowing the snowmobile **100** to travel in the forward direction of travel **122** and in the rearward direction of travel **124**. In some implementations, the drive track **114** and the snowmobile **100** may be slowed down via electrical braking (e.g., regenerative braking) implemented by the motor **170** and/or by a mechanical brake (e.g., a disc brake) connected to one of the track drive shaft **182** or the motor drive shaft **180**.

[0145] The snowmobile **100** may include a heat exchanger **132** that is coupled to, or integrated with, the tunnel **104**. The heat exchanger **132** may form part of a thermal management system to control the temperature of the battery **152**, the motor **170** and the charger **162**, for example. The heat exchanger may include channels to carry a thermal fluid along a portion of the tunnel **104**. During operation of the snowmobile **100**, the heat exchanger **132** may be exposed to snow and cold air circulating in the tunnel **104** that cools the thermal fluid. The thermal fluid may then be pumped through thermal channels in the battery **152**, the motor **170** and/or the charger **162**, for example, to cool those components. In some implementations, the thermal management system of the snowmobile **100** may also include a heater **168** (shown in FIG. **1**B) to heat the thermal fluid and warm the battery **152**. Warming the battery **152** may be useful if the snowmobile **100** has been left for an extended period in a cold environment. In such a case, the temperature of the battery cells in the battery modules **160** may fall to a level where high power is limited from being drawn from the battery **152**. Warming the battery **152** may bring the battery cells back into an efficient operating regime. In some implementations, the heater **168** is disposed within the battery enclosure **158**.

[0146] Referring again to FIG. **1**B, one or more controllers **190** (referred to hereinafter in the singular) and an instrument panel **134** are part of a control system for controlling operation of the snowmobile **100**. The instrument panel **134**

is an example of a user interface that allows an operator of the snowmobile **100** to generate user inputs and/or instructions for the snowmobile **100**. The controller **190** is connected to the instrument panel **134** to receive the instructions therefrom and perform operations to implement those instructions. In the illustrated embodiment, the instrument panel **134** is provided on the steering mechanism **144** and the controller **190** is disposed within the interior of the snowmobile **100**, but this need not always be the case.

[0147] The instrument panel **134** includes an accelerator **136** (also referred to as a "throttle") to allow an operator to control the power generated by the powertrain **150**. For example, the accelerator **136** may include a lever to allow the operator to selectively generate an accelerator signal. The controller **190** is operatively connected to the accelerator **136** and to the motor **170** to receive the accelerator signal and produce a corresponding output from the motor **170**. In some implementations, the accelerator signal is mapped to a torque of the motor **170**. When the controller **190** receives an accelerator signal from the accelerator **136**, the controller **190** maps the accelerator signal to a torque of the motor **170** and controls the power electronics module **174** to produce that torque using feedback from sensors in the motor **50**. The mapping of the accelerator signal to an output from the motor **170** may be based on a performance mode of the snowmobile **100** (e.g., whether the snowmobile **100** is in a power-saving mode, a normal mode or a high-performance mode). In some examples, the mapping of the accelerator signal to an output from the motor **170** may be based on current operating conditions of the powertrain **150** (e.g., temperature of the battery **152** and/or motor **170**, state of charge of the battery **152**, etc.). In still other examples, the mapping of the accelerator signal to an output from the motor **170** may be user configurable, such that a user may customize an accelerator position to motor output mapping.

[0148] In addition to the accelerator **36**, the instrument panel **34** may include other user input devices (e.g., levers, buttons and/or switches) to control various other functionality of the snowmobile **100**. These user input devices may be connected to the controller **190**, which executes the instructions received from the user input devices. Non-limiting examples of such user input devices include a brake lever to implement mechanical and/or electrical braking of the snowmobile **100**, a reverse option to propel the snowmobile **100** in the rearward direction of travel **124**, a device to switch the snowmobile **100** between different vehicle states (e.g., "off", "neutral" and "drive" states), a device to switch the snowmobile **100** between different performance modes, a device to switch between regenerative braking modes (e.g. "off", "low" and "high" modes) and a device to activate heating of handgrips of the steering mechanism. The snowmobile **100** also includes a display screen **138** connected to the controller **190**. The display screen **138** may be provided forward of the steering mechanism **144**, or in any other suitable location depending on the design of the snowmobile **100**. The display screen **138** displays information pertaining to the snowmobile **100** to an operator. Non-limiting examples of such information include the current state of the snowmobile **100**, the current performance mode of the snowmobile **100**, the speed of the snowmobile **100**, the state of charge (SOC) of the battery **152**, the angular speed of the motor **170**, and the power output from the motor **170**. The display screen **138** may include a liquid crystal display (LCD) screen, thin-film-transistor (TFT) LCD screen, light-emitting diode (LED) or other suitable display device. In some embodiments, display screen **138** may be touch-sensitive to facilitate operator inputs.

[0149] The controller **190** may also control additional functionality of the snowmobile **100**. For example, the controller **190** may control a battery management system (BMS) to monitor the SOC of the battery **152** and manage charging and discharging of the battery **152**. In another example, the controller **190** may control a thermal management system to manage a temperature of the battery **152**, the motor **170** and/or the charger **162** using a thermal fluid cooled by the heat exchanger **132** and/or heated by the heater **168**. Temperature sensors in the battery **152** and/or the motor **170** may be connected to the controller **190** to monitor the temperature of these components.

[0150] The controller **190** includes one or more data processors **192** (referred hereinafter as "processor **192**") and non-transitory machine-readable memory **194**. The memory **194** may store machine-readable instructions which, when executed by the processor **192**, cause the processor **192** to perform any computer-implemented method or process described herein. The processor **192** may include, for example, any type of general-purpose microprocessor or microcontroller, a digital signal processing (DSP) processor, an integrated circuit, an application-specific integrated circuit (ASIC), a field programmable gate array (FPGA), a reconfigurable processor, other suitably programmed or programmable logic circuits, or any combination thereof. The memory **194** may include any suitable machine-readable storage medium such as, for example, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination thereof. The memory **194** may be located internally and/or externally to the controller **190**.

[0151] Although the controller **190** is shown as a single component in FIG. **1B**, this is only an example. In some implementations, the controller **190** may include multiple controllers distributed at various locations in the snowmobile **100**. For example, the controller **190** may include a vehicle control unit (also referred to as a "body controller") that is responsible for interpreting the inputs from various other controllers in the snowmobile **100**. Non-limiting examples of these other controllers include a motor controller that is part of the power electronics module **174** and a battery management controller that is part of the battery **152**. Optionally, separate battery management controllers may be implemented in the each of the battery modules **160** to form a distributed battery management system.

[0152] Systems and methods are described and shown in the present disclosure in relation to the snowmobile **100**, but the present disclosure may also be applied to other types of vehicles, including other types of off-road and powersport vehicles.

[0153] Electric vehicles, including electric powersport vehicles, include power electronics systems that perform a wide variety of tasks to facilitate operation of the vehicle. These tasks include, inter alia, charging a main traction battery, charging a smaller ancillary battery, driving an electric motor, and powering numerous vehicle sub-systems. Some aspects of the present disclosure provide electronics system architectures that may perform these tasks efficiently, reliably, cost effectively, and/or with relatively few components. The electronics systems architectures disclosed herein may also improve functionality as compared to conventional systems.

[0154] The term "connected" or "coupled to" may include both direct connection or coupling (in which two elements contact each other) and indirect connection or coupling (in which at least one additional element is located between the two elements). Further, the term "connected" or "coupled to" may include electrical connections or couplings and/or mechanical connections or couplings. The term "substantially" as used herein may be applied to modify any quantitative representation which could permissibly vary without resulting in a change in the basic function to which it is related.

[0155] FIG. **2** is a block diagram illustrating a system **200** according to some embodiments of the present disclosure. The system **200** provides an example of a power electronics architecture (and partial powertrain) that may be implemented in an electric vehicle. For example, the system **200** may be implemented in, and/or in conjunction with, the powertrain **150** of the snowmobile **100**.

[0156] The system **200** includes a traction battery **202**, contactors **204**, a power electronics module **206**, an electric motor **208**, contactors **210**, a charging port **212**, a DC-to-DC converter **214**, one or more low-voltage systems **216**, an ancillary battery **218**, and one or more controllers **220**. The traction battery **202** may be the main high-voltage battery pack used to drive the electric motor **208** and propel an electric vehicle. Example implementations of the traction battery **202** are provided above with reference to the battery **152** of FIGS. **1A-1C**. As illustrated, the traction battery **202** is connected to the power electronics module **206** via contactors **204**. The contactors **204** are examples of high-voltage switches to selectively connect the traction battery **202** to the power electronics module **206** to provide the DC power to the power electronics module **206**. In this way, the contactors **204** may control the delivery of DC power from the traction battery **202** to the power electronics module **206**. When the electric vehicle is in an off state or in a charging mode, the contactors **204** may be open to disconnect the traction battery **202** from the power electronics module **206**. The contactors **204** may then be closed when the electric vehicle is switched an on state and/or a drive state to provide DC power to the power electronics module **206**. The power electronics module **206** may invert the DC power to drive the electric motor **208**.

[0157] The electric motor **208** and the power electronics module **206** are connected to the charging port **212** via the contactors **210**, which may include one or more high-voltage electrical switches or jump connections. In this way, the contactors **210** control when the charging port **212** is engaged with the rest of the system **200**. The contactors **210** may enable the system **200** to switch between different operating modes, which are discussed in further detail elsewhere herein.

[0158] The traction battery **202** is connected to the DC-to-DC converter **214**, which is an example of a voltage converter to buck (i.e., reduce) and/or boost (i.e., increase) the voltage of DC power supplied to and/or from the traction battery **202**. The DC-to-DC converter **214** is also connected to the power electronics module **206**, allowing power to flow between the traction battery **202** and the power electronics module **206** via the DC-to-DC converter **214**. The DC-to-DC converter **214** further is connected to the low-voltage systems **216** and to the ancillary battery **218**. In this way, the DC-to-DC converter **214** has three sides, which may be referred to as a primary side **214*a*** connected to the power electronics module **206**, a secondary side **214*b*** connected to the traction battery **202**, and a tertiary side **214*c*** connected to the low-voltage systems **216** and the ancillary battery **218**. The DC-to-DC converter **214** may be bi-directional such that current can flow from the primary side **214*a*** to the secondary side **214*b***, and from the secondary side **214*b*** to the primary side **214*a***. Current may flow to the tertiary side **214*c*** from the primary side **214*a*** and/or from the secondary side **214*b***. As discussed in further detail elsewhere herein, the bi-directionality and three sides of the DC-to-DC converter **214** enables the system **200** to perform a wide variety of functions.

[0159] The low-voltage systems **216** may include one or more components that use a 12V supply or another low-voltage supply. Similarly, the ancillary battery **218** may be a low-voltage battery (e.g., a 12V battery). The low-voltage systems **216** may be powered by the traction battery **202** via the DC-to-DC converter **214** when the DC-to-DC converter **214** is active. However, when the DC-to-DC converter **214** is inactive (e.g., when an electric vehicle is in an off state and/or when the electric vehicle is transitioning from the off state to an on state), the ancillary battery **218** may be used to power some or all of the low-voltage systems **216**.

[0160] The low-voltage systems **216** may include any number of different systems in an electric vehicle. Non-limiting examples of low-voltage systems include a thermal management system, a battery management system, and user interfaces. Although the low-voltage systems **216** are shown separately from other components in FIG. **2**, the low-voltage systems **216** may include or interact with one or more other components of the system **200**. For example, the DC-to-DC converter **214** may form part of a battery management system for an electric vehicle, and the low-voltage output provided by the DC-to-DC converter **214** may be used to power electronics (e.g., electrical switches) in the DC-to-DC converter **214** itself.

[0161] In the illustrated example, the low-voltage systems **216** include one or more controllers **220** to control the low-voltage systems **216** and/or other components of the system **200**. For example, the controllers **220** may control the contactors **204**, the power electronics module **206**, the contactors **210**, and/or the DC-to-DC converter **214**. The controllers **220** may include a body controller and/or a motor controller of an electric vehicle. Example implementations of the controllers **220** are provided above with reference to the controller **190** of FIGS. **1A-1C**.

[0162] As noted above, the system **200** may operate in and switch between multiple different operating modes. One such operating mode is an inverter mode. In the inverter mode, the charging port **212** is disconnected from the power electronics module **206** and from the electric motor **208** by the contactors **210**. As such, the charging port **212** might not interact with the rest of the system **200**. This may help ensure that high voltage from the traction battery **202** is not present at the charging port **212**. The power electronics module **206** may function as an inverter to drive the electric motor **208** using DC power delivered to the power electronics module **206** from the traction battery **202** via the contactors **204**. The low-voltage systems **216** and the ancillary battery **218** may be powered by the traction battery **202** via the DC-to-DC converter **214**. For example, power may flow from the secondary side **214***b* of the DC-to-DC converter **214** to the tertiary side **214***c*. The primary side **214***a* of the DC-to-DC converter **214** may be inactive (e.g., no power may flow through the primary side **214***a*) in the inverter mode.

[0163] The system **200** may also or instead operate in an external supply mode or a battery charging mode. In these modes, the contactors **210** may connect the charging port **212** to the power electronics module **206** and to the electric motor **208**. The charging port **212** allows the system **200** to connect to an external device, which may be a power source that provides power to the system **200** (e.g., to charge the traction battery **202**) or may be an external load that is powered by the system **200** (e.g., using power from the traction battery **202**). As such, the charging port **212** is not limited to connecting to charging stations or electric vehicle supply equipment (EVSE). More generally, the charging port **212** may include any electrical port implemented to enable an exchange of power to and/or from the system **200**. In some implementations, the charging port **212** may include a single port having multiple different connections for different external devices. Alternatively or additionally, the charging port **212** may include multiple different ports optionally positioned at different locations on an electric vehicle to enable connection to multiple different forms of external devices. For example, the charging port **212** may include AC and/or DC electric vehicle charging connectors (such as J1772 connectors, combined charging system (CCS) connectors, and/or North American charging standard (NACS) connectors), and/or standard 110V and/or 220V outlets.

[0164] When the system **200** is in the battery charging mode and the charging port **212** is connected to an external source of power, the power electronics module **206** and the electric motor **208** may function as a voltage converter (e.g., a buck-boost converter) to alter the voltage received at the charging port **212** to charge the traction battery **202**. If the source of power provides AC power to the charging port **212** (e.g., during level **1** or level **2** charging), then the power electronics module **206** and the electric motor **208** may also or instead rectify the AC power to produce DC power. The contactors **204** may be open during charging from an AC power source, and traction battery **202** may be charged via the DC-to-DC converter **214** to ensure isolation between the traction battery **202** and the AC power source. For example, the DC power from the power electronics module **206** may flow from the primary side **214***a* of the DC-to-DC converter **214** to the secondary side **214***b* to charge the traction battery **202**. The DC power from the power electronics module **206** may also or instead flow from the primary side **214***a* of the DC-to-DC converter **214** to the tertiary side **214***c* to power the ancillary system **216** and/or to charge the ancillary battery **218**.

[0165] If the charging port **212** is connected to a DC source of power (e.g., during level **3** or DC fast charging), then the DC power may flow directly from the charging port **212** to the traction battery **202** via the contactors **204**, which may be closed. The power electronics module **206** and electronic motor **208** may allow the DC power to passively flow to the traction battery **202** (e.g., without any active changes to the voltage). Alternatively, the power electronics module **206** and electronic motor **208** may actively boost the voltage of the DC power to match that of the traction battery **202** if, for example, the DC power source does not provide a voltage sufficient to charge the traction battery **202**. The DC-to-DC converter **214** might not be utilized for charging the traction battery **202** during DC charging, but may be utilized to power the low-voltage systems **216** and/or to charge the ancillary battery **218** (i.e., power flow from the primary side **214***a* to the tertiary side **214***c*).

[0166] When the charging port **212** is connected to an external load, the system **200** may enter the external supply mode. In this mode, the power electronics module **206** and the electric motor **208** may function as a voltage converter (e.g., a buck-boost converter) to alter a voltage output to the external load from the traction battery **202**. In some cases, the external load connected to the charging port **212** may be one or more devices requiring a single-phase AC power supply (e.g., a 110V or 220V supply at 50 Hz or 60 Hz). Non-limiting examples of such devices include power tools, lights, and cooking appliances. The external device connected to the charging port **212** need not be limited to a single appliance and might instead be a home or grid that is connected to the charging port **212**. To power the external device, DC power from the traction battery **202** may flow from the secondary side **214***b* to the primary side **214***a* of the DC-to-DC converter **214**, which may alter the voltage of the DC power. The power electronics module **204** and electric motor **206** may then covert (e.g., invert and/or buck or boost) DC power from the primary side **214**A of the DC-to-DC converter **214** to AC power having a voltage and/or frequency suitable to power the external device. This situation may generally be referred to as "vehicle-to-load" power transfer.

[0167] In some cases, the external load connected to the charging port **212** may include a device requiring a DC power supply. For example, the external load may be another vehicle having a high-voltage traction battery. The other vehicle may be connected to the charging port **212** to charge from the traction battery **202**. In such a case, DC power from the traction battery **202** may flow from the secondary side **214***b* to the primary side **214***a* of the DC-to-DC converter **214**. The DC-to-DC converter **214** may alter the voltage from the traction battery **202** to match that of the traction battery in the other vehicle. The power electronics module **206** and the electric motor **208** may be in a passive configuration to allow the DC power from the DC-to-DC converter **214** to flow to the charging port **212**. This situation may be referred to as "vehicle-to-vehicle" power transfer.

[0168] The ability of the system **200** to power/charge external loads may be useful when implemented in an off-road vehicle, as the traction battery **202** may serve as a powerpack that can be transported to remote locations by the off-road vehicle. The traction battery **202** may then power tools, homes and/or other electric vehicles in locations where power is limited.

[0169] As outlined above, the system **200** allows the power electronics module **206** and electric motor **208** to operate as both a charger for the battery **202** (in combination with the DC-to-DC converter **214**), a voltage converter for powering external loads, and as a tractive unit to propel an electric vehicle. In this way, the system **200** provides an integrated charger-inverter drivetrain. Advantageously, this allows the system **200** to operate without a dedicated charger, thereby reducing the number of components in the system **200**.

[0170] The system **200** may also operate in additional modes that provide advantages and efficiencies as compared to conventional power electronics architectures. In some implementations, the system **200** may operate in a pre-charging mode where the DC-to-DC converter **214** enables pre-charging a high-voltage bus connecting the contactors **204** and the power electronics module **206**. For example, DC power from the traction battery **202** may flow from the secondary side **214***b* to the primary side **214***a* of the DC-to-DC converter **214** to charge the high-voltage bus to a particular voltage level. This pre-charging may be performed before closing the contactors **204** to avoid an abrupt surge of current from the traction battery **202** to the power electronics module **206** that could damage components of the system **200**. For example, the contactors **204** could be welded shut by such a surge of current, thereby preventing the contractors **204** from being opened to turn-off an electric vehicle. Pre-charging the high-voltage bus connecting the contactors **204** and the power electronics module **206** may also, or instead, be performed before charging the traction battery **202** and/or before supplying power to an external device. Some conventional power electronics systems for electric vehicles include a dedicated pre-charger to charge a high-voltage bus, which is a component that may be prone to failure. Utilizing the DC-to-DC converter **214** to perform pre-charging may reduce the number of components needed and remove a mode of failure as compared to conventional power electronics systems utilizing a dedicated pre-charger.

[0171] In some embodiments, the system **200** may operate in one or mode fault tolerant modes when failures of certain components occur. These fault tolerant modes may help ensure that the failures of certain components will not render the system **200** and an electric vehicle inoperable. Fault tolerance may be beneficial in off-road vehicles that are driven in remote locations where assistance may be more difficult to obtain. As discussed in further detail elsewhere herein, the power electronics module **206** may include an extra set of electrical switches to help ensure that the electric motor **208** can still be driven in the event of one set of switches in the power electronics module **206** failing. Further, the DC-to-DC converter **214** may be used to power the power electronics module **206** and drive the electric motor **208** in the event that the contactors **204** cannot be closed, which may occur due to an issue with the contactors **204** themselves or an insulation fault in the system **200** that prevents the contractors **204** from being closed for safety reasons. In such an event, the DC-to-DC converter **214** may power the power electronics module **206** through power flow from the secondary side **214***b* to the primary side **214***a* while providing galvanic isolation.

[0172] Referring now to FIG. **3**, shown is a circuit diagram for the system **200** of FIG. **2**, according to an embodiment. FIG. **3** provides an example circuit implementation of the system **200**, however other implementations are also contemplated.

[0173] In the example of FIG. **3**, the traction battery **202** includes four battery modules V1, V2, V3, V4 connected in series, and the contactors **204** include two single pole, single throw (SPST) switches SPST1, SPST2. The positive terminal of the traction battery **202** is connected to the switch SPST1, which may form part of a first high-voltage bus **234***a* to connect the positive terminal of the traction battery **202** to the power electronics module **206**. The negative terminal of the traction battery **202** is connected to the switch SPST2, which may form part of a second high-voltage bus **234***b* to connect the negative terminal of the traction battery **202** to the power electronics module **206**.

[0174] It should be noted that the configuration of the traction battery **202** and contactors **204** in FIG. **3** is provided by way of example. In other implementations, different numbers and configurations of battery modules may be used in the traction battery **202**, and different numbers and types of switches may be used in the contactors **204**.

[0175] The power electronics module **206** shown in FIG. **3** includes a capacitor C5 and four sets of electrical switches **240***a*, **240***b*, **240***c*, **240***d*, which may all be connected in parallel across the high-voltage buses **234***a*, **234***b*. Each set of electrical switches **240***a*, **240***b*, **240***c*, **240***d* may include two electrical switches arranged in series between the high-voltage buses **234***a*, **234***b*, with a diode connected anti-parallel across each of the electrical switches. The diodes may be body diodes that are inherent to the electrical switches. In the illustrated example, the set of electrical switches **240***a* includes switches M2, M5 and body diodes D6, D9; the set of electrical switches **240***b* includes switches M3, M4 and body diodes D5, D8; the set of electrical switches **240***c* includes switches M1, M6 and body diodes D4, D7; and the set of electrical switches **240***d* includes switches M7, M8 and body diodes D1, D3. A discussed in further detail elsewhere herein, this four-leg topology for the power electronics module **206** may enable two-phase operation in the case that there is a fault at any of the three motor phases (e.g., a fault in any of the sets of electrical switches **240***a*, **240***b*, **240***c*).

[0176] In some implementations, the switches M1-M8 are silicon carbide metal-oxide-semiconductor field-effect transistors (MOSFETs) that may exhibit relatively short rise and fall times and high blocking voltages. Other implementations of the power electronics module **206** are also contemplated. For example, the switches M1-M8 may include insulated gate bipolar transistors (IGBTs) and/or may include other semiconductor platforms such as silicon or gallium nitride.

[0177] The electric motor **208** may be a three-phase permanent magnet synchronous motor including three phase windings L5, L6, L7. The phase windings L5, L6, L7 (also referred to as "motor windings") may be provided in the stator of the electric motor **208** and may each connect to a neutral point **238** of the electric motor **208**. Each of the phase windings L5, L6, L7 may also connect to the power electronics module **206**. The phase winding L6 may be connected to the set of electrical switches **240***a*, between the switches M2, M5. The phase winding L5 may be connected to the set of electrical switches **240***b*, between the switches M3, M4. The phase winding L7 may be connected to the set of electrical switches **240***c*, between the switches M1, M6. The electrical current through each of the phase windings L6, L5, L7 may be measured by a respective current sensor X1, X2, X3 in the power electronics module **206** to help facilitate motor control and/or battery charging. The current sensors X1, X2, X3 may include non-invasive means of current measurement such as Hall-effect current sensors, for example.

[0178] The contactors **210** may include two single pole, double throw (SPDT) switches SPDT1, SPDT2. In other embodiments, three SPST switches may be implemented in place of the switches SPDT1, SPDT2. The switch SPDT1 may be used to selectively connect a terminal **236***a* of the charging port **212** to the neutral point **238** and the switch

SPDT2 may be used to selectively connect another terminal **236***b* of the charging port **212** to the power electronics module **206**. For example, the common side of the switch SPDT1 may be connected to the neutral point **238** of the electric motor **208**, the normally closed side of the switch SPDT1 may be connected to the terminal **236***a* of the charging port **212**, and the normally open side of the switch SPDT1 may be connected to the normally open side of the switch SPDT2. The normally closed side of the switch SPDT2 may be connected to the terminal **236***b* of the charging port **212**. The common side of the switch SPDT2 may be connected to the set of electrical switches **240***d*, and in particular may be connected between the switches M7, M8. In the illustrated example, a resistor R1 is implemented between the common side of the switch SPDT2 and the set of electrical switches **240***d* as a shunt based high-frequency current sensor. In operation, the contactors **210** may selectively connect the terminal **236***a* of the charging port **212** to the neutral point **238** of the electric motor **208** and/or may selectively connect the terminal **236***b* of the charging port **212** to the power electronics module **206** (e.g., to the set of electrical switches **240***d*). The contactors **210** may also selectively connect the set of electrical switches **240***d* to the neutral point **238**.

[0179] Other embodiments of the contactors **210** are also contemplated. For example, the contactors **210** may include a jump connector integrated with a charging cap of the charging port **212** such that, when the charging cap is closed, the jump connector automatically connects the neutral point **238** of the electric motor **208** to the power electronics module **206**. When the charging cap is opened (e.g., when an external device is connected to the charging port **212**), the jump connector automatically disconnects the neutral point **238** of the electric motor **208** from the power electronics module **206**. In this way, the position of the charging cap may switch the system **200** between various operational modes, as discussed in further detail elsewhere herein.

[0180] The charging port **212** of FIG. **3** may include five connections (also referred to as "terminals") to connect the system **200** to one or more external devices, such as to an external power supply and/or to an external load, for example. The five connections include may two connections for receiving/supplying DC power, namely a positive DC connection DC+ and a negative DC connection DC−. The five connections may also include three connections for receiving/supplying AC power, namely a live (or hot) connection L, a neutral connection N, and a ground (or earth) connection E. In some implementations, the connections DC+, DC−, L, E, N may be provided by a CCS connector or other type of standardized electrical vehicle charging connector. In some implementations, the charging port **212** may include more or fewer than five connections. In some implementations, the charging port **212** may include other connections such as one or more data connections to allow an external device to communicate with a controller (e.g., the controllers **220**) of the system **200** and/or of an electric vehicle.

[0181] As illustrated, the positive DC connector DC+ is connected directly to the terminal **236***a* of the charging port **212** and the negative DC connector DC− is connected directly to the terminal **236***b*. The charging port **212** may include an integrated electromagnetic interference (EMI) filter **230** connecting the live connection L and neutral connection N to the terminals **236***a*, **236***b*. The EMI filter **230** may remove noise and unwanted signals from the electrical power propagating through the charging port **212** to protect the system **200** and/or to protect an external device connected to the charging port **212**. In some implementations, the EMI filter **230** may be an AC power line filter, for example. The EMI filter may include several capacitors C1, C2, C3, C4, several inductors L1, L2, L3, L4, and a common mode choke T1. The capacitor C1 may be connected between the terminals **236***a*, **236***b* of the charging port **212**. The capacitors C3, C4 may be connected in series between the live connection L and the neutral connection N. The ground connection E may be connected between the capacitors C3, C4. The ground connection E may connect to earth from an AC power source and may also connect to the chassis of an electric vehicle. The capacitor C2 may also be connected between the live and neutral connections L, N, in parallel with the capacitors C3, C4. The inductors L2, L3 may be connected in series between the live connection L and the first terminal **236***a* of the charging port **212**. The inductors L1, L4 may be connected in series between the neutral connection L and the second terminal **236***b* of the charging port **212**. The inductors L1, L2 may form the windings of the common mode choke T1, which may be implemented in parallel with the capacitor C1, between the terminals **236***a*, **236***b*.

[0182] The size, type, and other characteristics of the capacitors C1-C4, inductors L1-L4, and common mode choke T1 are not limited herein and may vary based on the implementation of the system **200**. It should also be noted that the EMI filter **230** shown in FIG. **3** is provided only by way of example. Other EMI filter configurations are also contemplated. In some embodiments, the charging port **212** might not include an EMI filter at all.

[0183] FIG. **3** shows an example of the DC-to-DC converter **214** in circuit form, including the primary side **214***a*, the secondary side **214***b* and the tertiary side **214***c*. The primary side **214***a*, the secondary side **214***b*, and the tertiary side **214***c* may each be connected via a transformer (or transformer core) T2 of the DC-to-DC converter **214**. In some implementations, the DC-to-DC converter **214** may be or include a half-bridge LLC converter. However, other implementations of the DC-to-DC converter **214** are also contemplated.

[0184] The primary side **214***a* may be connected to the first high-voltage bus **234***a* and the second high-voltage bus **234***b* of the system **200**, at a position between the contactors **204** and the power electronics module **206**. The primary side **214***a* may include capacitors C6, C7, C8, inductors L8, L9, L10, electric switches M9, M10 and body diodes D2, D10. The capacitor C7 may be connected between the high-voltage bus **234***a* and the high-voltage bus **234***b*. In the illustrated example, the capacitor C7 is an electrolytic capacitor. The capacitors C6, C8 may also be connected in series between the high-voltage buses **234***a*, **234***b*, in parallel with the capacitor C7. Further, the electrical switches M9, M10 may be connected in series between the high-voltage buses **234***a*, **234***b*, also in parallel with the capacitor C7 and the capacitors C6, C8. The body diodes D2, D10 may be inherent elements of the electrical switches M9, M10 that are connected anti-parallel across the electrical switches M9, M10, respectively. As shown, the inductors L8, L9, L10 may form the primary transformer winding of the transformer T2. The inductor L8 may be the leakage inductance component of the primary side winding and the inductor L9 may be the magnetization inductance component of the primary side winding. The inductor L8 may be connected between the electrical switches M9, M10 and the inductors L9, L10 may be connected between the capacitors C6, C8.

[0185] As discussed in further detail elsewhere herein, the primary side **214***a* may function as an inverter to convert DC power from the high-voltage buses **234***a*, **234***b* into AC power that may be conveyed through the transformer T2. Additionally, the primary side **214***a* may function as a rectifier to convert AC power conveyed through the transformer T2 into DC power for the high-voltage buses **234***a*, **234***b*.

[0186] The secondary side **214***b* may be connected to the positive and negative terminals of the traction battery **202**. The secondary side **214***b* may include capacitors C10, C11, inductors L13, L14, electrical switches M11, M12, and body diodes D13, D14. The capacitors C10, C11 may be connected in series between the positive and negative terminals of the traction battery **202**. The electrical switches M11, M12 may also be connected in series between the positive and negative terminals of the traction battery **202**, in parallel with capacitors C10, C11. The body diodes D13, D14 may be inherent elements of the electrical switches M11, M12 that are connected anti-parallel across the electrical switches M11, M12, respectively. The inductors L13, L14 may form the secondary transformer winding of the transformer T2, where the inductor L13 may be the leakage inductance component of the secondary side winding. The inductor L13 may be connected between the electrical switches M12, M12, and the inductor L14 may be connected between the capacitors C10, C11.

[0187] Similar to the primary side **214***a*, the secondary side **214***b* may function as an inverter to convert DC power from the traction battery **202** into AC power that may be conveyed through the transformer T2. The secondary side **214** may also or instead function as a rectifier to convert AC power conveyed through the transformer T2 into DC power to charge the traction battery **202**. As power can be conveyed from the primary side **214***a* to the secondary side **214***b*, and from the secondary side **214***b* to the primary side **214***a*, the DC-to-DC converter **214** may be a bi-directional DC-to-DC converter.

[0188] In some embodiments, electrical switches may be connected between the traction battery **202** and the secondary side **214***b* of the DC-to-DC converter to selectively connect/disconnect the traction battery **202** from the secondary side **214***b*.

[0189] The tertiary side **214***c* of the DC-to-DC converter **214** may include two inductors L11, L12 that form the tertiary windings of the transformer T2. In some implementations, the two inductors L11, L12 may form a center tapped transformer. The tertiary side **214***c* may also include a DC regulator **232** (also referred to as a DC post regulator) having a first input **232***a* and a second input **232***b*, a capacitor C9 (illustratively an electrolytic capacitor), and two diodes D11, D12. The capacitor C9 may be connected between the first input **232***a* and the second input **232***b* of the DC regulator **232**. The inductor L12 may be connected to the first input **232***a* via the diode D11, and the inductor L11 may also be connected to the first input **232***a* via the diode D12. The second input **232***b* may be connected between the inductors L11, L12.

[0190] The tertiary side **214***c* may function as a passive (e.g., non-switching) rectifier to convert AC power from the transformer T2 to DC power. The DC regulator **232** may regulate the DC output from the tertiary side **214***c* to a defined voltage, which is 12V in the illustrated example. The 12V output may be provided to the low-voltage systems **216** and/or the ancillary battery **218**. In some implementations, the DC regulator **232** is a buck-boost converter that can convert a DC power between 6 and 18V received across the first input **232***a* and second input **232***b* to 12V.

[0191] In the illustrated example, the electrical switches M9-M12 are shown as MOSFETs, however other types of transistors may also or instead be used. The electrical switches M9-M12 may be build on a silicon platform or another semiconductor platform. The size, type, and other characteristics of the capacitors C6-C11, inductors L8-L14, and transformer T2 are not limited herein and may vary based on the implementation of DC-to-DC converter **214**.

[0192] As discussed above, the system **200** may operate in any one of multiple possible modes depending on the state of the system **200** and/or on commands from an operator. Example operational modes of the system **200** will now be described.

[0193] The inverter mode of the system **200** may be used to drive the electric motor **208** and propel an electric vehicle in response to accelerator commands from an operator, for example. In some implementations, the inverter mode may correspond to a drive state of the electric vehicle. The inverter mode may only be operable by the system **200** when the charging port **212** is disconnected from any external devices.

[0194] The inverter mode may be configured by closing the switches SPST1, SPST2 to connect the power electronics module **206** to the traction battery **202** via the high-voltage buses **234***a*, **234***b*. The sets of switches **240***a*, **240***b*, **240***c* in the power electronics module **206** may then invert DC power from the traction battery **202** to produce AC power to drive the electric motor **208**. The set of switches **240***d* may be inactive in the inverter mode, such that the switches M7, M8 are not actively converting DC power from the traction battery **202** to AC power to drive the electric motor **208**. In some implementations, the switches M7, M8 are open in the inverter mode.

[0195] In the inverter mode, the charging port **212** may be disconnected from the remainder of the system **200** using the contactors **210**. For example, the switch SPDT1 may disconnect the terminal **236***a* of the charging port **212** from the neutral point **238** of the electric motor **208** and the switch SPDT2 may disconnect the terminal **236***b* of the charging port **212** from the set of switches **240***d* in the power electronics module **206**. Further, the switches SPDT1, SPDT2 may connect the neutral point **238** of the electric motor **208** to the power electronics module **206**. Alternatively, the neutral point **238** may be floating (i.e., not connected to anything other than the phase windings L5, L6, L7). The phase windings L5, L6, L7 may provide a balanced current at the neutral point **238**.

[0196] In the inverter mode, the DC-to-DC converter **214** may be operating to supply power to the low-voltage systems **216**. For example, power may flow from the secondary side **214***b* to the tertiary side **214***c* to produce a 12V supply for the low-voltage systems **216**.

[0197] The inverter mode may correspond to a mode where no component failures are detected in the system **200**, allowing the system **200** to operate in a normal fashion. However, the system **200** may also include additional operating modes that allow operation in the event of certain faults. In some embodiments, the system **200** may operate in an inverter fault tolerant mode that enables operation of the system **200** when one or more components of the power electronics module **206** are non-functional. For example, in some cases, one of the sets of switches **240***a*, **240***b*, **240***c* may be non-functional due to one or more of the switches M1-M6 failing. The failure of an electrical switch such as a MOSFET might be a rare occurrence, but is still a possibility. When one of the sets of the switches **240***a*, **240***b*, **240***c* is non-functional, the corresponding phase (also referred to as "leg") of the electric motor **208** may also be non-functional. As such, only two of the phase windings L5, L6, L7 may be operational to drive the electric motor **208**. In the inverter fault tolerant mode, when one set of the electrical switches **240***a*, **240***b*, **240***c* is non-functional, the system **200** may use the remaining two sets of electrical switches to convert DC power from the traction battery **202** to AC power to drive the electric motor **208**. This may be referred to herein as two-phase operation of the electric motor **208**.

[0198] To facilitate two-phase operation in the inverter fault tolerant mode, the set of electrical switches **240***d* is connected to the neutral point **238** of the electric motor **208** via the contactors **210**. For example, the switches SPDT1, SPDT2 may each be switched from the configuration shown in FIG. **3** to connect the mid-point of the set of electrical switches **240***d* to the neutral point **238**. The set of electrical switches **240***d* may then provide a path for imbalanced current at the neutral point **238** back to the traction battery **202**. This imbalanced current may occur as a result of the two-phase operation of the electric motor **208**, where there is no active third phase to balance the current. The switches M7, M8 may operate (i.e., switch at an appropriate duty cycle) to provide a current path from the neutral point **238** to one of the high-voltage buses **234***a*, **234***b* based of the phase of the current at the neutral point **238**. In this way, the set of switches **240***d* may maintain neutral operation of the neutral point **238** to help ensure that the electric motor **208** is operable.

[0199] Although operating the system **200** in the inverter fault tolerant mode may provide limited performance capabilities as compared to the normal inverter mode, the inverter fault tolerant mode may still allow the electric motor **208** to be driven and propel an electric vehicle. This may allow a user to drive the electric vehicle to a location where the necessary repairs to the power electronics module **206** may be performed. In contrast, conventional electric vehicles that have a power electronics module with only three sets of electric switches may be inoperable in the event that one of the sets of switches fails. For example, in such an electric vehicle, current imbalance at the neutral point of an electric motor during two-phase operation may render the electric motor inoperable.

[0200] The system **200** may also operate in another fault tolerant mode, referred to as an insulation fault tolerant mode, when an insulation failure is detected between the traction battery **202** and other components of an electric vehicle (e.g., the chassis). Such an insulation failure may be detected by an insulation monitoring device (IMD), for example. When an insulation failure is detected, the contactors **204** may be opened to disconnect the traction battery **202** for safety reasons. The insulation fault tolerant mode may still enable the system **200** to drive the electric motor **208** when the contactors **204** are open by providing power to the power electronics module **206** from the traction battery **202** via the DC-to-DC converter **214**. For example, power may flow from the secondary side **214***b* to the primary side **214***a* to power the power electronics module **206**. As such, the transformer T2 of the DC-to-DC converter **214** may provide galvanic isolation between the traction battery **202** and the high-voltage buses **234***a*, **234***b* when operating in the insulation fault tolerant mode for improved safety.

[0201] Due to power limitations of the DC-to-DC converter **214**, the insulation fault tolerant mode of the system **200** may provide limited performance capabilities as compared to the normal inverter mode. However, the insulation fault tolerant mode may still allow the electric motor **208** to be driven to propel an electric vehicle, which may allow an operator to drive the electric vehicle to a location where repairs can be performed.

[0202] In the inverter fault tolerant mode and the insulation fault tolerance mode, similar to the inverter mode, the DC-to-DC converter **214** may be operating to supply power to the low-voltage systems **216** from the secondary side **214***b* via the tertiary side **214***c*.

[0203] The system **200** may operate in one of the inverter mode, the inverter fault tolerant mode, or the insulation fault tolerance mode when the charging port **212** is disconnected from an external device. In some implementations, when an external device is connected to the charging port **212**, the system **200** may be restricted from operation in the inverter mode, the inverter fault tolerant mode, or the insulation fault tolerant mode. The system **200** may instead operate in a battery charging mode or an external supply mode. Optionally, operation of the electric motor **208** may be disabled (e.g., the electric motor **208** may be in a logic neutral state) when an external device is connected to the charging port **212**, where accelerator commands from a user are disabled or ignored.

[0204] In some implementations, the battery charging mode and the external supply mode may only be entered upon an external device being connected to the charging port **212**. For example, when the charging port **212** is connected to the external device, the contactors **210** may connect the terminal **236***a* of the charging port **212** to the neutral point **238** of the electric motor **208** and connect the terminal **236***b* of the charging port **212** to the set of switches **240***d* of the power electronics module **206**. Connecting the charging port **212** to the motor **208** and the power electronics module **206** in this manner may be performed automatically in response to an external device being connected to the charging port **212**. For example, logic executed by a controller (e.g., the controllers **220**) and/or an analog circuit may operate the contactors **210** to configure the system **200** in the battery charging mode or the external supply mode when an external device is detected at the charging port **212**.

[0205] Similarly, in some implementations, disconnecting the charging port **212** from the motor **208** and the power electronics module **206** for the inverter mode and fault tolerant modes may also be performed automatically in response to an external device being disconnected from the charging port **212**. Logic executed by a controller and/or an analog circuit may operate the contactors **210** to enable the inverter modes and fault tolerant modes when no external device is detected at the charging port **212**.

[0206] Referring to the battery charging mode for the system **200**, the charging port **212** may be connected to an external charger providing AC power or DC power. When the charger provides AC power, the electric motor **208** and power electronics module **206** may act to rectify and boost the AC power to produce DC power across the high-voltage buses **234***a*, **234***b*. For example, the motor **208** and the power electronics module **206** may function as a totem-pole bridgeless power factor correction (PFC) circuit. The three phase windings L5, L6, L7 may be used in parallel as a single boost inductor, and the three sets of switches **240***a*, **240***b*, **240***c* may be synchronized to function as a single switch for one leg of the totem-pole bridgeless PFC. The set of switches **240***d* may function as the other leg of the totem-pole bridgeless PFC. In this way, the electric motor **208** and the power electronics module **206** may form the PFC stage of an integrated charger in the system **200** to provide DC power across the high-voltage buses **234***a*, **234***b*. In some implementations, the PFC stage may boost the root mean square (RMS) voltage of the incoming AC power by between 1.4 times and 10 times.

[0207] When the external charger provides AC power to the charging port **212**, the switches SPST1, SPST2 may be open to galvanically isolate the traction battery **202** from the charger **212**. Power flow may be conducted through the DC-to-DC converter **214** to charge the traction battery **202**. For example, DC power across the high-voltage buses **234***a*, **234***b* may be transferred from the primary side **214***a* to the secondary side **214***b* of the DC-to-DC converter **214**. The voltage across the high-voltage buses **234***a*, **234***b* may be altered (e.g., bucked or boosted) by the DC-to-DC converter **214** based on an SOC and/or a voltage of the traction battery **202** to charge the traction battery **202** according to a certain charging methodology (e.g., constant current or constant voltage charging). For example, the duty cycles of the switches M9, M10 at the primary side **214***a* and/or the switches M11, M12 at the secondary side **214***b* may be controlled based on the voltage of the traction battery **202**. Power may also be transferred from the primary side **214***a* to the tertiary side **214***c* to power the low-voltage systems **216**.

[0208] As outlined above, the configuration of the system **200** enables the contactors **210** to switch the function of the power electronics module **206** from a motor inverter for propelling an electric vehicle to a boost converter for charging the electric vehicle. As such, the power electronics module **206** and the electric motor **208** may play at least two important roles in the system **200** that are conventionally performed by different components. This may reduce the weight, cost and complexity of the system **200** as compared to conventional power electronics architectures for electric vehicles.

[0209] When the external charger provides DC power, the electric motor **208** and power electronics module **206** may be passive components that enable the DC power to flow directly from the charging port to the high-voltage buses **234***a*, **234***b*. For example, the switches M1, M3, M5, M8 may be closed and the switches M2, M4, M6, M7 may be open. Alternatively, the electric motor **208** and power electronics module **206** may function as a boost converter to boost the DC voltage according to a voltage/SOC of the traction battery **202** and a charging methodology, for example. The switches SPST1, SPST2 may also be closed to enable power to flow directly to the traction battery **202** to charge the battery.

[0210] Although current is flowing through the phase windings L5, L6, L7 of the electric motor **208** in the battery charging mode, the electric motor **208** should not move as the currents flowing through the phase windings L5, L6, L7 are all in phase and equal in magnitude. Therefore, there is no rotating magnetic field and zero torque will be produced in the electric motor **208**. In the case that the electric motor **208** does move in the battery charging mode for any reason, an encoder in the electric motor **208** may detect the movement and trigger a fault that disconnects the electric motor **208** from the charging port **212** using the contactors **210**.

[0211] Referring now to the external supply mode for the system **200**, the charging port **212** may be connected to an external device requiring AC power or DC power. In some implementations, an adaptor may be connected to the charging port **212** to configure the system **200** in the external supply mode. The adaptor may include data connections that provide signals indicating the power requirements of the external device. For example, the data connections may configure the system **200** to output 110V AC power, 220V AC power, or DC power from the charging port **212**.

[0212] The switches SPST1, SPST2 may be open in the external supply mode, and the DC-to-DC converter **214** may be used to provide DC power to the high-voltage buses **234***a*, **234***b*. For example, power from the traction battery **202** may flow from the secondary side **214***b* of the DC-to-DC converter **214** to the primary side **214***a*. The tertiary side **214***c* may also receive power from the secondary side **214***b* in the external supply mode. The DC-to-DC converter **214** may alter the voltage from the traction battery **202** based on the voltage requirements of the external device. If the external load is requesting AC power, then the power electronics module **206** may invert the DC power to produce AC power for the external load. The sets of switches **240***a*, **240***b*, **240***c* may act as one leg of the inverter, and the set of switches **240***d* may act as the other leg of the inverter. Alternatively, if the external device is requesting DC power, then the power electronics module **206** may passively provide the DC power to the charging port **212** from the DC-to-DC converter **214** by closing switches M1, M3, M5, M8 and opening switches M2, M4, M6, M7, for example.

[0213] A further mode of the system **200** is a pre-charge mode that may utilize the DC-to-DC converter **214** to slowly and safely pre-charge the high-voltage buses **234***a*, **234***b* and the capacitor C5 to a desired voltage before the buses **234***a*, **234***b* are connected to a high-voltage source. For example, the pre-charging mode may be used before the switches SPST1, SPST2 are closed during every turn-on of the system **200** or before entering the inverter mode, the battery charging mode and/or the external supply mode. The pre-charge mode may use the DC-to-DC converter **214** to transfer battery power from the secondary side **214***b* to the primary side **214***a* to charge the high-voltage buses **234***a*, **234***b*. The duty cycle of the switches M11, M12 on the secondary side **214***b* and the switches M9, M10 on the primary side **214**A may be modulated to control the current flowing to the buses **234***a*, **234***b* to avoid a surge of current. Pre-charging may be performed until a desired voltage is achieved across the buses **234***a*, **234***b*. After pre-charging the buses **234***a*, **234***b* is complete, the pre-charge mode may be exited in favor of the inverter mode, battery charging mode, or external supply mode, for example.

[0214] To further illustrate the various operating modes of the system **200**, FIG. **4** provides a flow diagram illustrating a method **300** of selecting an operating mode from the multiple possible operating modes of the system **200**, according to an embodiment. The method **300** will be described as being performed by the controllers **220** of the system **200**. However, other controllers and/or systems may implement the method **300**.

[0215] At block **302**, the controllers **220** determine whether or not an external device is connected to the charging port **212**. This determination may be made based on a position of a charging cap for the charging port **212**. If the charging cap is open, then it may be determined that an external device is connected. Alternatively, if the charging port is closed, then it may be determined that an external device is not connected. The determination may also or instead be based on whether or not data signals from the external device are received at the charging port **212**. If no external device is connected to the charging port **212**, then the method **300** proceeds to block **304**.

[0216] At block **304**, the controllers **220** determine whether there is a fault at the power electronics module **206**. An example of such a fault is one of the sets of electrical switches **240***a*, **240***b*, **240***c* being non-functional. Detecting a fault may be based on inputs from one or more sensors in the system **200**, such as the current sensors X1-X3. If no current is detectable at one of the phase windings L5-L7, then it may be determined that a corresponding set of switches is non-functional. If no fault in the power electronics module **206** is detected, then the method **300** proceeds to block **306**.

[0217] At block **306**, the controllers **220** determine whether there is an insulation fault in the system **200**. An insulation fault may be detected by an IMD. If no insulation fault is detected, then the method **300** may proceed to blocks **310**, **312**.

[0218] At optional block **310**, the system **200** may enter the pre-charge mode to charge the high-voltage buses **234***a*, **234***b* and the capacitor C5. However, block **310** may be omitted if pre-charging is not required. Next, at block **312**, the system **200** enters the inverter mode in which the electric motor **208** may be driven based on accelerator commands from an operator, for example.

[0219] Referring again to block **304**, if a non-function set of switches is detected at the power electronics module **206**, then method **300** may proceed to optional block **314** and to block **316**. At block **314**, the system **200** may enter the pre-charge mode as required. At block **316**, the system **200** may enter the inverter fault tolerance mode to drive the electric motor **208** using two-phase operation.

[0220] If instead there is an insulation fault detected at block **306**, then the method **300** may proceed to optional block **318** and to block **320**. At block **318**, the system **200** may enter the pre-charge mode. At block **320**, the system **200** may enter the insulation fault tolerance mode to drive the electric motor **208** while galvanically isolating the traction battery **202**.

[0221] Referring again to block **302**, if the controllers **220** determine that there is an external device connected to the charging port **212**, then the method **300** may proceed to block **322** where it is determined whether the external device is a charger, and/or proceed to block **328** where it is determined whether the external device is a load. The determination at blocks **322**, **328** may be based on data signals received from the external device, for example.

[0222] If the external device is a charger, then the method **300** may proceed from block **322** to optional block **324** where the pre-charging mode may be entered, and then to block **326**. At block **326**, the system **200** enters the battery charging mode to charge the traction battery **202** from the charger.

[0223] If the external device is an external load, then the method **300** may proceed from block **328** to optional block **330** where the pre-charging mode may be entered, and then to block **332**. At block **332**, the system **200** enters the external supply mode where power from the traction battery **202** may be provided to the external load.

[0224] It should be noted the method **300** is only an example implementation of operating modes of the system **200**. Other methods for selecting an operating mode for the system **200** are also contemplated. For example, in some embodiments, an operating mode may be selected based on user input through a user interface.

[0225] Various additional methods that may be performed by the system **200** will now be described.

[0226] FIG. **5** is a flow diagram illustrating a method **400**, according to an embodiment. The method **400** will be described as being performed by the system **200**, but the method **400** may also be performed by other electronics systems for electric vehicles.

[0227] Block **402** includes connecting the neutral point **238** of the electric motor **208** to the power electronics module **206** to drive the electric motor **208**, which may include connecting the neutral point **238** between the electrical switches M7, M8 using the contactors **210**, as shown in FIG. **3**. Optional block **404** then includes operating the power electronics module **206** to invert DC power from the traction battery **202** to produce AC power to drive the electric motor **208**. For example, block **404** may be performed in response to accelerator signals from an accelerator of the electric vehicle.

[0228] Blocks **402**, **404** may correspond to the inverter mode for the system **200**, and might only be performed when an external device is disconnected from the charging port **212**. In block **406**, the system **200** determines whether an external device is connected to the charging port **212**. Block **406** might be similar to block **302** of FIG. **4**, for example. If an external device is not connected, then the method **400** may return to blocks **402**, **404**. The method **400** may cycle through blocks **402**, **404**, **406** to continuously check for external devices and, responsive to an external device being connected, proceed to blocks **408**, **410**.

[0229] Block **408** includes connecting the neutral point **238** of the electric motor **208** to the terminal **236***a* of the charging port **212**, and block **410** includes connecting the power electronics module **206** to the terminal **236***b* of the charging port **212**. For example, the set of switches **240***d* may be connected to the terminal **236***b*, and more particularly the terminal **236***b* may be between the electrical switches M7, M8, as shown in FIG. **3**. It should be noted that the order of blocks **408**, **410** in FIG. **5** is shown by way of example only. From blocks **408**, **410**, the method **400** may proceed to either block **412** or block **414** depending on the type of external device connected.

[0230] If the external device is a charger providing AC power, then the method **400** may proceed to block **412**, which includes operating the power electronics module to rectify and boost the AC power to produce DC power to charge the traction battery **202**. For example, the three sets of electrical switches **240***a*, **240***b*, **240***c* may be operated as at least part of a first leg of a rectifier and the fourth set of electrical switches **240***d* may be operated as at least part of a second leg of the rectifier. Block **412** may also include operating the DC-to-DC converter **214** to alter a voltage of the DC power to charge the traction battery **202**, to reduce the voltage of the DC power to power the low-voltage systems **216**, and/or galvanically isolate the traction battery **202** from the charging port **212**, as discussed in further detail elsewhere herein. In this way, block **412** may correspond to the battery charging mode of the system **200**. Block **412** may also include operating the DC-to-DC converter **214** to pre-charge the capacitor C5 using the traction battery **202** prior to charging the traction battery **202** (i.e., operating in the pre-charge mode of the system **200**). Further, block **412** may include filtering electromagnetic interference using the EMI filter **230** integrated in the charging port **212**.

[0231] If the external device is a load requesting power from the system **200**, then the method **400** may proceed to block **414** from blocks **408**, **410**. Block **414** includes operating the power electronics module **206** to invert DC power from the traction battery **202** to produce AC power for the external load. For example, the three sets of electrical switches **240***a*, **240***b*, **240***c* may be operated as at least part of a first leg of an inverter and the fourth set of electrical switches **240***d* may be operated as at least part of a second leg of the inverter. Block **414** may further include operating the DC-to-DC converter **214** to alter a voltage of the DC power from the traction battery **202** for the external load.

[0232] Following blocks **412**, **414**, the method **400** may proceed back to block **406** to check if the external device is still connected to the charging port **212**. Responsive to the external device being disconnected from the charging port **212**, the method **400** may proceed back to blocks **402**, **404** to reconnect the neutral point **238** of the electric motor **208** to the power electronics module **206**.

[0233] FIG. **6** is another flow diagram illustrating a method **500**, according to an embodiment. The method **500** will be described as being performed by the system **200**, but the method **500** may also be performed by other electronics systems for electric vehicles.

[0234] At block **502**, the system **200** may convert DC power from the traction battery **202** to three-phase AC power using the three sets of electrical switches **240***a*, **240***b*, **240***c* in the power electronics module **206**. The fourth set of switches **240***d* may be inactive when converting the DC power from the traction battery **202** to three-phase AC power. Block **504** then includes driving the electric motor **208** with the three-phase AC power. Blocks **502**, **504** may correspond to the inverter mode of the system **200**.

[0235] Block **506** includes determining if there is a fault at the power electronics module **206**, which may include one of the sets of electrical switches **240***a*, **240***b*, **240***c* being non-functional. In some implementations, block **506** may include measuring current at each of the phase windings L5-L7 (e.g., using the current sensors X1-X3) to determine if the sets of electrical switches **240***a*, **240***b*, **240***c* are operating correctly. If no fault is detected, then the method **500** may return to blocks **502**, **504**. Block **506** may be performed cyclically to check for faults. While blocks **502**, **504** are shown sequentially in FIG. **6**, it is noted that these blocks may be performed simultaneously in some implementations.

[0236] Responsive one of the three sets of electrical switches **240***a*, **240***b*, **240***c* being non-functional at block **506**, the method **500** may proceed to blocks **508**, **510**, **512**. Block **508** includes converting the DC power from the traction battery to two-phase AC power using the remaining two sets of electrical switches, and block **510** includes driving the electric motor **208** with the two-phase AC power. Block **512** includes balancing current at the neutral point **238** of the electric motor **208** using the fourth set of electrical switches **240***d* in the power electronics module **206**. For example, the fourth set of electrical switches **240***d* may be operated to provide a current path from the neutral point **238** to the traction battery **206**, which may include operating (e.g., switching) the switches M7, M8 to provide a current path from the neutral point **238** to high-voltage buses **234***a*, **234***b* based on the polarity of current at the neutral point **238**. Blocks **508**, **510**, **512** may correspond to the inverter fault tolerant mode of the system **200**. While blocks **508**, **510**, **512** are shown sequentially in FIG. **6**, it is noted that these blocks may be performed simultaneously. For example, converting the DC power to two-phase AC power, driving the electric motor **208** and balancing current at the neutral point **238** may be performed continuously in the fault tolerant mode, responsive to an accelerator signal from an operator.

[0237] FIG. **7** is a further flow diagram illustrating a method **600**, according to an embodiment. The method **600** will be described as being performed by the system **200**, but the method **600** may also be performed by other electronics systems for electric vehicles.

[0238] Block **602** includes transferring power from the traction battery **204** to the power electronics module **206** using the DC-to-DC converter **214** or, more generally, any form of voltage converter. Block **602** may correspond to the pre-charge mode, the external supply mode and the insulation fault tolerant mode of the system **200**. In some implementations, block **602** includes inverting, using the secondary side **214***b*, a first DC power from the traction battery **202** to produce AC power at the transformer T2 and rectifying, using the primary side **214***a*, the AC power from the transformer T2 to provide a second DC power for the power electronics module **206**. The voltage of the second DC power may be greater than or less than the voltage of the first DC power. For example, if the charging port **212** is connected to an external load, then a duty cycle of the electrical switches M9, M10 at the primary side **214***a* and/or a duty cycle of the electrical switches M11, M12 at the secondary side **214***b* may be adjusted based on a voltage requirement of the external load. This may buck or boost the voltage from the traction battery **202** to match the voltage requirement of the external load.

[0239] Block **604** includes transferring power from the power electronics module **206** to the traction battery **204** using the DC-to-DC converter **214**, which may occur during the battery charging mode of the system **200**. Block **604** may include inverting, using the primary side **214***a*, a first DC power from the power electronics module **206** to produce AC power at the transformer T2 and rectifying, using the secondary side **214***b*, the AC power from the transformer T2 to provide a second DC power to charge the traction battery **202**. A duty cycle of the electrical switches M9, M10 at the primary side **214***a* and/or a duty cycle of the electrical switches M11, M12 at the secondary side **214***b* may be adjusted to control the voltage of the second DC power based on a voltage needed to charge the traction battery **202**.

[0240] Block **608** includes transferring power from the power electronics module **206** or the traction battery **202** to the low-voltage systems **216** using the DC-to-DC converter

214. Block **608** may occur during any, one, some or all operational modes of the system **200**. Block **608** may include inverting a first DC power from the power electronics module **206** to produce AC power at the transformer T2 using the primary side **214***a*, or inverting a first DC power from the traction battery **202** to produce the AC power at the transformer T2 using the secondary side **214***b*. The AC power from the transformer T2 may be rectified by the tertiary side **214***c* to provide a second DC power to power the low-voltage systems. The DC-to-DC converter **214** may reduce the voltage at the primary side **214***a* or the secondary **214***b* for the low-voltage systems **216**. Further, the DC regulator **232** may regulate a voltage of the second DC power for the low-voltage systems **216**.

[0241] The methods **400**, **500**, **600** are shown by way of example only. Other methods may also be performed by the system **200**. It should also be noted that any two or more of the methods **400**, **500**, **600** may be implemented in conjunction by the system **200**.

[0242] Systems and methods of charging multiple electric vehicles from a single EVSE will now be provided. Such systems and methods may be useful where the demand for EVSEs exceeds the number available.

[0243] FIG. **8** is a block diagram illustrating multiple electric vehicles **800***a*, **800***b*, **800***c* connected to and being charged by a single EVSE **804**, according to an embodiment. As is described in detail below, FIG. **8** illustrates an example of "daisy-chain" charging multiple electric vehicles from a single source of power. Daisy-chain charging may be implemented to allow each of the electric vehicles **800***a*, **800***b*, **800***c* to connect the EVSE **804** at once. Each of the electric vehicles **800***a*, **800***b*, **800***c* may then be charged simultaneously and/or sequentially. This may avoid operators having to monitor the charge state of the electric vehicles **800***a*, **800***b*, **800***c* and manually switch the EVSE **804** between the electric vehicles **800***a*, **800***b*, **800***c* as charging is completed. Daisy-chain charging may be particularly useful in the case that the multiple electric vehicles **800***a*, **800***b*, **800***c* need to be charged overnight from a single EVSE.

[0244] Any one or more of the electric vehicles **800***a*, **800***b*, **800***c* may be similar to the electric snowmobile **100** of FIGS. **1A-1C**, but other embodiments of electric vehicles are also contemplated. Each of the electric vehicles **800***a*, **800***b*, **800***c* includes a respective charging port **802***a*, **802***b*, **802***c*, which may be similar to the charging port **212** in the system **200** and/or may include a standardized charging connector such as a J1772 connector, a combined charging system (CCS) connector, and/or North American charging standard (NACS) connector, for example. Each of the charging ports **802***a*, **802***b*, **802***c* is connected to the EVSE **804** to receive electrical power from the EVSE **804**.

[0245] The EVSE **804** has a power output **806** for charging the electric vehicles **800***a*, **800***b*, **800***c*. The power output **806** may include an electrical cable with a connector (or plug) at one end for connecting to a charging port of an electric vehicle. In some implementations, the EVSE **804** may enable level **1**, level **2** and/or level **3** (DC fast) charging through the power output **806**. For example, the power connection may include the live, neutral and ground connections for level **1** and level **2** charging, and/or include positive and negative DC connections for level **3** charging. Although only one power output **806** is shown in FIG. **8**, the EVSE **804** may more generally include multiple power outputs.

[0246] In addition to the power output **806**, the EVSE **804** also has a data connection **808** for communicating with an electrical vehicle to facilitate charging. For example, the data connection **808** may indicate to the EVSE **804** that the power output **806** is connected to an electric vehicle and also indicate the charging parameters. The power output **806** and data connection **808** may be provided within a single cable from the EVSE **804** and connect to electrical vehicles using a single connector.

[0247] As shown, the power output **806** and data connection **808** from the EVSE **804** may be connected to each of the electric vehicles **800***a*, **800***b*, **800***c* using two charging adaptors **804***a*, **804***b*. The adaptors **804***a*, **804***b* may each be a form of electrical splitter that splits the power output **806** and data connection **808** to the three electric vehicles **800***a*, **800***b*, **800***c* such that each of the electric vehicles **800***a*, **800***b*, **800***c* may be charged by the EVSE **804**.

[0248] The adaptor **804***a* includes three ports **810***a*, **812***a*, **814***a*. The port **810***a* may function as an input port that receives power from the power output **806** of the EVSE **804**. The received power may then be provided to either or both of the ports **812***a*, **814***a*. The port **812***a* is connected to the charging port **802***a* of the electric vehicles **800***a*, which may allow the electrical vehicle **800***a* to be charged from the power output **806**. The port **814***a* is connected to the other adaptor **804***b* to transfer power to the other electric vehicles **800***b*, **800***c*.

[0249] Similar to the adaptor **804***a*, the adaptor **804***a* also includes three ports **810***b*, **812***b*, **814***c*. The port **810***b* is connected to the port **814***a* of the adaptor **804***a*, allowing power to be received from the power output **806**. The adaptor **804***b* may then distribute the power to the charging port **802***b* of electric vehicle **800***b* via the port **812***b*, and/or to the charging port **802***c* of electric vehicle **800***c* via the port **814***b*. In this way, the adaptors **804***a*, **804***b* may split the power output **806** to each of the electric vehicles **800***a*, **800***b*, **800***c*. For example, each of the charging ports **802***a*, **802***b*, **802***c* may be connected in parallel to the power output **806**.

[0250] The adaptors **804***a*, **804***b* may also split the data connection **808** to each of the electric vehicles **800***a*, **800***b*, **800***c*. For example, the port **810***a* may include a terminal to connect to the data connection **808**, and each of the other ports **812***a*, **814***a*, **810***b*, **812***b*, **814***b* may also include data terminals to form data connections between the adaptors **804***a*, **804***b* and the electric vehicles **800***a*, **800***b*, **800***c*. These data connections may enable each of the adaptors **804***a*, **804***b* and/or the electric vehicles **800***a*, **800***b*, **800***c* to communicate with each other and/or with the EVSE **804** to facilitate charging. For example, each of the charging ports **802***a*, **802***b*, **802***c* may be connected in series to the data connection **808**. In some cases, communications along the data connection **808** may inform the EVSE **804** and the electric vehicles **800***a*, **800***b*, **800***c* that they are in a daisy-chain configuration.

[0251] Cables may be used to interconnect the adaptors **804***a*, **804***b* and the electric vehicles **800***a*, **800***b*, **800***c* for the power output **806** and the data connection **808**. One or more of these cables may be part of the adaptors **804***a*, **804***b*, or may be separate cables that attach to the ports of the adaptors **804***a*, **804***b*.

[0252] Various methodologies may be implemented to charge the electric vehicles **800***a*, **800***b*, **800***c* when connected to the EVSE **804** via the adaptors **804***a*, **804***b*, as shown in FIG. **8**. In some implementations, the electric vehicles **800**a, **800**b, **800**c may be charged sequentially. The sequence of charging may be selected based on the order that the electric vehicles **800**a, **800**b, **800**c are connected to the EVSE **804**. For example, the electric vehicle **800**c may be charged first as it is the last vehicle in the row, followed by electrical vehicle **800**b and then electric vehicle **8020**a. Alternatively, the order of charging may be selected by a user using interfaces on the EVSE **804**, the adaptors **804**a, **804**b and/or the electric vehicles **800**a, **800**b, **800**c.

[0253] In other implementations, all three of the electric vehicles **800**a, **800**b, **800**c may be charged simultaneously by the EVSE **804** by splitting the power from the power output **806** to each of the charging ports **802**a, **802**b, **802**c. The power in the power output **806** may be split evenly between each of the electric vehicles **800**a, **800**b, **800**c. However, the power need not be split evenly in all implementations. For example, the power to each of the electric vehicles **800**a, **800**b, **800**c may be adjusted based on the SOC of each vehicle such that the electric vehicles **800**a, **800**b, **800**c complete charging at similar times.

[0254] The charging and power distribution to the electric vehicles **800**a, **800**b, **800**c from the power output **806** may be controlled in any of a number of different ways. In some implementations, the adaptors **804**a, **804**b do not actively control charging and passively distribute power to each of the charging ports **802**a, **802**b, **802**c. As such, voltage from the power output **806** may be present at each of the charging ports **802**a, **802**b, **802**c. The electric vehicles **800**a, **800**b, **800**c themselves may then implement a defined methodology for daisy-chain charging. For example, if the electric vehicles **800**a, **800**b, **800**c are to be charged sequentially starting with the electric vehicle **800**c, then the electrical vehicle **800**c may implement charging while the electric vehicles **800**a, **800**b may prevent charging until it is their turn.

[0255] Alternatively or additionally, the adaptors **804**a, **804**b may actively deliver power only to the one or more electric vehicles that are scheduled to be charged, and may also control the power delivered to each of the electric vehicles. In some embodiments, the adaptors **804**a, **804**b include controllers, power converters and/or switches to control charging. These controllers may include one or more processors and memory storing computer-readable instructions executable by the processors. Examples of processors and memory are provided elsewhere herein.

[0256] It should be noted that FIG. **8** is provided by way of example only, and other implementations of charging multiple electric vehicles from the EVSE **804** are also contemplated. For example, more or fewer than three electric vehicles may be connected to the EVSE **804** as needed. More or fewer adaptors may be implemented in response to electric vehicles being connected or disconnected from the EVSE **804**. Further, the adaptors **804**a, **804**b need not be limited to three ports, and may include additional ports to connect to other adaptors and/or electric vehicles.

[0257] The embodiments described in this document provide non-limiting examples of possible implementations of the present technology. Upon review of the present disclosure, a person of ordinary skill in the art will recognize that changes may be made to the embodiments described herein without departing from the scope of the present technology.

What is claimed is:

1. A system for an electric vehicle, the system comprising:
a battery;
a power electronics module to connect to the battery;
an electric motor comprising a plurality of phase windings and a neutral point, each of the plurality of phase windings connected between the power electronics module and the neutral point;
a port to connect to an external device, the port comprising a first terminal and a second terminal; and
at least one electrical switch to selectively connect the first terminal of the port to the neutral point of the electric motor and to selectively connect the second terminal of the port to the power electronics module.

2. The system of claim **1**, wherein the at least one electrical switch is to connect the first terminal of the port to the neutral point of the electric motor and to connect the second terminal of the port to the power electronics module when the port is connected to the external device.

3. The system of claim **2**, wherein:
the external device comprises a charger providing alternating current (AC) power; and
the electric motor and the power electronics module are to rectify and boost the AC power to charge the battery.

4. The system of claim **2**, wherein:
the external device comprises an external load; and
the port is to transfer power from the battery to the external load.

5. The system of claim **4**, wherein the power electronics module is to invert direct current (DC) power from the battery to produce alternating current (AC) power for the external load.

6. The system of claim **2**, wherein the at least one electrical switch is to disconnect the first terminal of the port from the neutral point of the electric motor and to disconnect the second terminal of the port from the power electronics module when the port is disconnected from the external device.

7. The system of claim **6**, wherein the at least one electrical switch is to connect the neutral point of the electric motor to the power electronics module when the port is disconnected from the external device.

8. The system of claim **6**, wherein when the port is disconnected from the external device, the power electronics module is to invert direct current (DC) power from the battery to produce alternating current (AC) power to drive the electric motor.

9. The system of claim **1**, wherein:
the plurality of phase windings comprises three phase windings;
the power electronics module comprises three sets of electrical switches connected to three phase windings, respectively; and
the power electronics module further comprises a fourth set of electric switches to connect to the second terminal the port.

10. The system of claim **9**, wherein:
the system comprises a first bus and a second bus connecting the battery to the power electronics module;
the fourth set of electrical switches comprises a first electrical switch and a second electrical switch connected in series between the first bus and the second bus; and
the at least one switch is to connect the second terminal of the port between the first electrical switch and the second electrical switch of the fourth set of electrical switches.

11. A system for an electric vehicle, the system comprising:
- an electric motor comprising three phase windings connected to a neutral point;
- a power electronics module comprising three sets of electrical switches connected to the three phase windings, respectively, and a fourth set of electrical switches to connect to the neutral point;
- a battery to connect to the power electronics module; and
- a port to connect to the neutral point and to the fourth set of switches.

12. The system of claim **11**, wherein the three sets of electrical switches are to convert direct current (DC) power from the battery to alternating current (AC) power to drive the electric motor.

13. The system of claim **12**, wherein when the three sets of electrical switches are converting DC power from the battery to AC power to drive the electric motor, the port is disconnected from the neutral point and disconnected from the fourth set of electrical switches.

14. The system of claim **12**, wherein when the three sets of electrical switches are converting DC power from the battery to AC power to drive the electric motor, the fourth set of electrical switches is inactive.

15. The system of claim **11**, wherein when the three sets of electrical switches comprise a non-functional set of switches, the remaining two sets of electrical switches are to convert DC power from the battery to AC power to drive the electric motor.

16. A method for an electric vehicle comprising an electric motor, a power electronics module, and a port, the method comprising:
- connecting a neutral point of the electric motor to the power electronics module to drive the electric motor; and
- responsive to an external device being connected to the port:
  - connecting the neutral point of the electric motor to a first terminal of the port, and
  - connecting the power electronics module to a second terminal of the port.

17. The method of claim **16**, wherein the external device comprises a charger providing alternating current (AC) power, the method comprising:
- operating the power electronics module to rectify and boost the AC power to produce direct current (DC) power to charge a battery of the electric vehicle.

18. The method of claim **16**, wherein the external device comprises an external load, the method comprising:
- operating the power electronics module to invert direct current (DC) power from a battery of the electric vehicle to produce alternating current (AC) power for the external load.

19. The method of claim **16**, comprising:
- responsive to the external device being disconnected from the port, reconnecting the neutral point of the electric motor to the power electronics module.

20. The method of claim **16**, comprising:
- operating the power electronics module to invert direct current (DC) power from a battery of the electric vehicle to produce alternating current (AC) power to drive the electric motor when the external device is disconnected from the port.

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