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Module-based energy systems capable of cascaded and interconnected configurations, and methods related thereto

Abstract

Module-based energy systems are provided having multiple converter-source modules. The converter-source modules can each include an energy source and a converter. The systems can further include control circuitry for the modules. The modules can be arranged in various ways to provide single phase AC, multi-phase AC, and/or DC outputs. Each module can be independently monitored and controlled.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. application Ser. No. 17/463,793, filed Sep. 1, 2021, which is a continuation of U.S. application Ser. No. 16/832,812, filed Mar. 27, 2020, now U.S. Pat. No. 11,135,923, which claims the benefit of and priority to U.S. Provisional Application Ser. No. 62/826,158, filed Mar. 29, 2019, U.S. Provisional Application Ser. No. 62/826,238, filed Mar. 29, 2019, and U.S. Provisional Application Ser. No. 62/906,007, filed Sep. 25, 2019, all of which are incorporated by reference herein for all purposes.

FIELD

(1) The subject matter described herein relates generally to module-based energy systems and modules for use therein, and systems, devices, and methods that facilitate the connection and control of modules in module-based energy systems.

BACKGROUND

(2) Energy systems having multiple energy sources or sinks are commonplace in many industries. One example is the automobile industry. Today's automotive technology, as evolved over the past century, is characterized, amongst many things, by an interplay of motors, mechanical elements, and electronics. These are the key components that impact vehicle performance and driver experience. Motors are of the combustion or electric type and one usually finds one motor per car, exceptions being cars with hybrid drivetrains, featuring a combination of a combustion engine with one or two electric motors, or performance oriented electric vehicles that are outfitted with two motors. In almost all cases the rotational energy from the motor(s) is delivered via a set of highly sophisticated mechanical elements, such as clutches, transmissions, differentials, drive shafts, torque tubes, couplers, etc. These parts control to a large degree torque conversion and power distribution to the wheels and are key elements to define the performance of the car. They also impact road handling. Over the years individual car manufacturers have highly optimized these mechanical parts to provide better performance, higher fuel efficiency and ultimately differentiation in the market place. On the control side, apart from driver comforts such as entertainment, navigation and human machine interface elements, there are typically only a few clusters of specialty electronics hardware and embedded software that control/optimize motors, clutch/transmission operation and road holding/handling.

(3) An EV includes various electrical systems that are related to the drivetrain including, among others, the battery, the charger and motor control. A short inventory of the present capabilities and shortcomings of these electrical systems are described below.

(4) Conventional Battery Design

(5) High voltage battery packs are typically organized in a serial chain of lower voltage battery modules. Each such module further includes a serially connected set of individual cells and a simple embedded battery management system to regulate basic cell related characteristics, such as state of charge and voltage. Electronics with more sophisticated capabilities or some form of smart interconnectedness are absent. As a consequence, any monitoring or control function is handled by a separate system, which, if at all present elsewhere in the car, lacks the ability to monitor individual cell health, state of charge, temperature and other performance impacting metrics. There is also no ability to adjust power draw per individual cell in any form. Some of the major consequences are: (1) the weakest cell constrains the overall performance of the entire battery pack, (2) failure of any cell or module leads to a need for replacement of the entire pack, (3) battery reliability and safety are considerably reduced, (4) battery life is limited, (5) thermal management is difficult, (6) battery packs always operate below maximum capabilities, (7) sudden inrush into the battery packs of regenerative braking derived electric power cannot be readily stored in the batteries and will require dissipation via a dump resistor.

(6) Conventional Charger Design

(7) Charging circuits are typically realized in separate on-board systems. They stage power coming from outside the EV in the form of an AC signal or a DC signal, convert it to DC and feed it to the battery pack(s). Charging systems monitor voltage and current and typically supply a steady constant feed. Given the design of the battery packs and typical charging circuits, there is little ability to tailor charging flows to individual battery modules based on cell health, performance characteristics, temperature, etc. Charging cycles are also typically long as the charging systems and battery packs lack the circuitry to allow for pulsed charging or other techniques that would optimize the charge transfer or total charge achievable.

(8) Conventional Motor Control Design

(9) Conventional controls contain DC to DC conversion stages to adjust battery pack voltage levels to the bus voltage of the EV's electrical system. Motors, in turn, are then driven by simple two-level multiphase converters that provide the required AC signal(s) to the electric motor. Each motor is traditionally controlled by a separate controller, which drives the motor in a 3-phase design. Dual motor EVs would require two controllers, while EVs using four in-wheel motors would require 4 individual controllers. The conventional controller design also lacks the ability to drive next generation motors, such as switch reluctance motors (SRM), characterized by higher numbers of pole pieces. Adaptation would require higher phase designs, making the systems more complex and ultimately fail to address electric noise and driving performance, such as high torque ripple and acoustical noise.

(10) Many of these deficiencies apply not only to automobiles but other motor driven vehicles, and also to stationary applications to a certain extent. For these and other reasons, needs exist for improved systems, devices, and methods for energy systems for mobile and stationary applications.

SUMMARY

(11) Example embodiments of systems, devices, and methods are provided herein for module-based energy systems widely relevant to many applications. In many of these embodiments, a module-based energy system includes multiple modules, where each module includes at least an energy source and a converter. More complex configurations of each module are also disclosed. The modules of the system can be connected together in different arrangements of varying complexities to perform functions specific to the particular technological application to which the system is applied. The system can be configured to monitor status information, at least one operating characteristic, or other parameter of each module repeatedly during use of the system, assess the state of each module based on that monitored status information, operating characteristic, or other parameter, and control each module independently in an effort to achieve and/or maintain one or more desired targets, such as electrical performance, thermal performance, lifespan, and others. This control can occur to facilitate energy provision from the system (e.g., discharging) and/or energy consumption (e.g., charging). Numerous example applications of these systems, devices, and methods are described.

(12) In many example embodiments, the at least one energy source of the module can include a capacitor (such as an ultra-capacitor or super-capacitor), a battery, or a fuel-cell.

(13) In many example embodiments, the system can include at least two converter-source modules connected in a one-dimensional array or in a multi-dimensional array. At least two one-dimensional arrays can be connected together, for example, at different rows and columns directly or by one or more additional converter-source modules. In such configurations, an output voltage of any shape and frequency can be generated at the outputs of the module-based energy system as a superposition of output voltages of individual converter-source modules.

(14) In many example embodiments, the system includes one or more interconnection modules capable of selectively supplying power to one of two or more arrays of modules. The interconnection module permits the efficient exchange of energy between arrays and also can be used to compensate for imbalances of operating parameters, such as state of charge or temperature, occurring between different arrays. Interconnection module thus can be used for inter-array balancing. If those arrays are dedicated to producing output waveforms of different phase angles, then the interconnection module can be used for inter-phase balancing.

(15) The various interconnected architectures of the example embodiments enable inter-array or inter-phase power management within a single module-based energy system (e.g., a battery pack) and inter-system power management between multiple module-based energy systems (e.g., battery packs), as well as connection of auxiliary loads to the system(s), and maintenance of uniform distribution of energy provided to those loads from all converter-source modules of such systems.

(16) The various connected architectures of the example embodiments also enable the control of

power sharing among converter-source modules. Such control enables, for example, regulation of parameters like State of Charge of the energy sources of the converter-source modules to be balanced, in real time and continually during cycling, as well as at rest, which fosters utilization of the full capacity of each energy source regardless of possible differences in their capacities. In addition, such control can be used to balance the temperature of the energy sources of the converter-source modules. Temperature balancing, for example, can increase the power capability of the system (e.g., a battery pack) and provide more uniform aging of the energy sources regardless of their physical location within the system and differences in their thermal resistivity.

(17) Other systems, devices, methods, features and advantages of the subject matter described herein will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the subject matter described herein, and be protected by the accompanying claims. In no way should the features of the example embodiments be construed as limiting the appended claims, absent express recitation of those features in the claims.

Description

BRIEF DESCRIPTION OF FIGURES

(1) The details of the subject matter set forth herein, both as to its structure and operation, may be apparent by study of the accompanying figures, in which like reference numerals refer to like parts. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the subject matter. Moreover, all illustrations are intended to convey concepts, where relative sizes, shapes and other detailed attributes may be illustrated schematically rather than literally or precisely.

(2) FIGS. **1**A, **1**B and **1**C are block diagrams depicting example embodiments of a module-based energy system.

(3) FIG. **2** is a block diagram depicting an example embodiment of a converter-source module (ConSource V**1**) with a local control device (LCD) connected to a master control device (MCD), according to embodiments of the present disclosure.

(4) FIG. **3** is a block diagram depicting another example embodiment of a converter-source module (ConSource V**2**) with an LCD connected to an MCD, according to embodiments of the present disclosure.

(5) FIG. **4** is a block diagram depicting another example embodiment of a converter-source module (ConSource V**3**) with an LCD connected to an MCD and optional auxiliary loads, according to embodiments of the present disclosure.

(6) FIG. **5**A is a schematic depicting an example embodiment of a converter (Converter V**1**) shown in FIG. **2**, according to embodiments of the present disclosure.

(7) FIG. **5**B is a schematic depicting an example embodiment of a converter (Converter V**2**) shown in FIGS. **2** and **3**, according to embodiments of the present disclosure.

(8) FIGS. **6**A, **6**B and **6**C are diagrams depicting example embodiments of energy storage elements for use as an energy source shown in FIGS. **1**, **2** and **3**, according to embodiments of the present disclosure.

(9) FIGS. **7**A, **7**B and **7**C are schematics depicting of example embodiments for use as the energy buffer shown in FIGS. **1**, **2** and **3**, according to embodiments of the present disclosure.

(10) FIGS. **8**A, **8**B, **8**C, **8**D, **8**E, and **8**F are diagrams depicting example embodiments for use as energy source **2** shown in FIG. **3**, according to embodiments of the present disclosure.

(11) FIG. **9** is a graph depicting the output voltage from an example converter according to embodiments of the present disclosure.

(12) FIG. **10** is a graph depicting the output voltage from an example module-based energy storage system having six example converter-source modules, according to embodiments of the present disclosure.

(13) FIG. **11** is a block diagram depicting an example embodiment of power flow management for the example converter-source module (ConSource V**2**) shown in FIG. **3**, according to embodiments of the present disclosure.

(14) FIGS. **12**A and **12**B are graphs depicting example waveforms of a converter-source (ConSource V**2**) module shown in FIG. **3**, in which the converter V**2** provides a secondary function of reduction of a second order current harmonic.

(15) FIG. **13** is a block diagram depicting an example embodiment of power flow management for the converter-source (ConSource V**3**) module shown in FIG. **4**, according to embodiments of the present disclosure.

(16) FIGS. **14**A, **14**B, **14**C, and **14**D are graphs depicting an example embodiment of pulse width modulation applicable to example embodiments of module-based energy systems.

(17) FIG. **15** is a schematic depicting an example one-dimensional array of connected example converter-source modules, according to example embodiments of the present disclosure.

(18) FIG. **16** is a schematic depicting an example two-dimensional array of connected example converter-source modules, according to example embodiments of the present disclosure.

(19) FIG. **17** is a schematic depicting another example two-dimensional array of connected example converter-source modules, according to example embodiments of the present disclosure.

(20) FIG. **18** is a schematic depicting an example system having multiple example converter-source modules connected in a three-dimensional array, according to example embodiments of the present disclosure.

(21) FIG. **19** is a schematic depicting another example system having multiple example converter-source modules connected in a three-dimensional array, according to example embodiments of the present disclosure.

(22) FIG. **20** is a schematic depicting another example system having multiple example converter-source modules connected in a three-dimensional array, according to example embodiments of the present disclosure.

(23) FIG. **21** is a schematic depicting an example system having multiple example converter-source modules connected in a multi-dimensional array, according to example embodiments of the present disclosure.

(24) FIG. **22** is a schematic depicting an example system having multiple example converter-source modules connected in a three-dimensional array, and connected to an electrical motor, according to example embodiments of the present disclosure.

(25) FIG. **23** is a schematic depicting another example system having multiple example converter-source modules connected in a three-dimensional array, and connected to an electrical motor, according to example embodiments of the present disclosure.

(26) FIG. **24** is a schematic depicting another example system having multiple example converter-source modules connected in a three-dimensional array, and connected to an electrical motor and auxiliary loads, according to example embodiments of the present disclosure.

(27) FIG. **25** is a schematic depicting another example system having multiple example converter-source modules connected in a three-dimensional array, and connected to an electrical motor and auxiliary loads, according to example embodiments of the present disclosure.

(28) FIG. **26** is a schematic depicting another example system having multiple example converter-source modules connected in a six-dimensional array, and connected to a six-phase electrical motor and auxiliary loads, according to example embodiments of the present disclosure.

(29) FIGS. **27**A and **27**B are schematics depicting additional example systems having multiple example converter-source modules connected in three-dimensional arrays, and connected to multiple three-phase electrical motors and auxiliary loads, according to example embodiments of

the present disclosure.

(30) FIG. **28** is a schematic depicting another example system having multiple example converter-source modules connected in a three-dimensional array, and connected to a three-phase open-winding electrical motor and auxiliary loads, according to example embodiments of the present disclosure.

(31) FIG. **29** illustrates a schematic depicting another example system having multiple example converter-source modules connected in a three-dimensional array, and connected to two three-phase open-winding electrical motors and auxiliary loads, according to example embodiments of the present disclosure.

(32) FIG. **30** is a schematic depicting an example embodiment of a single-phase balancing controller, for use with example embodiments of the present disclosure.

(33) FIG. **31** depicts a phasor diagram of voltage sharing control for an example single-phase system, for use with example embodiments of the present disclosure.

(34) FIG. **32** depicts a schematic depicting an example embodiment of a single-phase balancing controller, for use with example embodiments of the present disclosure.

(35) FIGS. **33**A and **33**B depict phasor diagrams of voltage sharing control for a three-phase structure for (A) intra-phase balancing only and (B) intra-phase and inter-phase balancing.

(36) FIGS. **34**A and **34**B depict phasor diagrams of voltage sharing control for a three-phase structure with interconnection modules (or common modules) with intra-phase and inter-phase balancing through (A) common modules and (B) common modules and neutral point shift.

(37) FIGS. **35**A and **35**B depict phasor diagrams of voltage sharing control with intra-phase and inter-phase balancing for four-phase systems with (A) neutral point shift and (B) interconnection modules and neutral point shift.

(38) FIGS. **36**A and **36**B depict phasor diagrams of voltage sharing control with intra-phase and inter-phase balancing for five-phase systems with (A) neutral point shift and (B) interconnection modules and neutral point shift.

(39) FIGS. **37**A and **37**B depict phasor diagrams of voltage sharing control with intra-phase and inter-phase balancing for six-phase systems with (A) neutral point shift and (B) interconnection modules and neutral point shift.

(40) FIGS. **38**A and **38**B depict phasor diagrams of voltage sharing control with intra-phase and inter-phase balancing for an example system shown in FIG. **27** through (A) interconnection modules and (B) interconnection modules and neutral point shift.

(41) FIGS. **39**A and **39**B depict phasor diagrams of voltage sharing control with intra-phase and inter-phase balancing for systems shown in FIG. **28** through (A) interconnection modules and (B) interconnection modules and neutral point shift.

(42) FIGS. **40**A and **40**B depict phasor diagrams of voltage sharing control with intra-phase and inter-phase balancing for systems shown in FIG. **29** through (A) interconnection modules and (B) interconnection modules and neutral point shift.

(43) FIGS. **41**A-**41**F are block and schematic diagrams depicting example embodiments of energy supply systems with interconnection modules.

(44) FIGS. **42**A-**42**B are flow diagrams depicting example embodiments of methods of performing inter-phase balancing with an interconnection module.

(45) FIGS. **43**A-**43**C are block diagrams depicting example embodiments of a converter-source module.

(46) FIGS. **44**A and **44**B are schematic diagrams depicting example embodiments of a components of a converter-source module mounted on one or more substrates.

DETAILED DESCRIPTION

(47) Before the present subject matter is described in detail, it is to be understood that this disclosure is not limited to the particular embodiments described, as such may, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular

embodiments only, and is not intended to be limiting, since the scope of the present disclosure will be limited only by the appended claims.

(48) Example embodiments of module-based energy systems are described herein, as are: example embodiments of devices, circuitry, software, and components within such systems; example embodiments of methods of operating and using such systems; and example embodiments of applications (e.g., apparatuses, machines, grids, locales, structures, environments, etc.) in which such systems can be implemented or incorporated or with which such systems can be utilized. In many cases, these applications can be classified as a mobile application or a stationary application.

Examples of Applications

(49) Mobile applications are generally ones where a module-based energy system is located on or within an entity, and stores and provides electrical energy for conversion into motive force by a motor to move or assist in moving that entity. Examples of mobile entities with which the embodiments disclosed herein can be used include, but are not limited to, electric and/or hybrid entities that move over or under land, over or under sea, above and out of contact with land or sea (e.g., flying or hovering in the air), or through outer space. Examples of mobile entities with which the embodiments disclosed herein can be used include, but are not limited to, vehicles, trains, ships, vessels, aircraft, and spacecraft. Examples of mobile vehicles with which the embodiments disclosed herein can be used include, but are not limited to, those having only one wheel or track, those having only two-wheels or tracks, those having only three wheels or tracks, those having only four wheels or tracks, and those having five or more wheels or tracks. Examples of mobile entities with which the embodiments disclosed herein can be used include, but are not limited to, a car, a bus, a truck, a motorcycle, a scooter, an industrial vehicle, a mining vehicle, a flying vehicle (e.g., a plane, a helicopter, a drone, etc.), a maritime vessel (e.g., commercial shipping vessels, ships, yachts, boats or other watercraft), a submarine, a locomotive or rail-based vehicle (e.g., a train, etc.), a military vehicle, a spacecraft, and a satellite.

(50) Stationary applications are generally applications other than mobile applications. Generally, in stationary applications the module-based energy system resides in a static location while providing electrical energy for consumption by one or more other entities. Examples of stationary applications in or with which the embodiments disclosed herein can be used include, but are not limited to: energy systems for use by or within one or more residential structures or locales, energy systems for use by or within one or more industrial structures or locales, energy systems for use by or within one or more commercial structures or locales, energy systems for use by or within one or more governmental structures or locales (including both military and non-military uses), and systems that convert solar power, wind, geothermal energy, fossil fuels, or nuclear reactions into electricity for storage. Examples of stationary applications in or with which the embodiments disclosed herein can be used include, but are not limited to: energy systems for charging the mobile applications described above (e.g., a charging station). Other examples of stationary applications in or with which the embodiments disclosed herein can be used include, but are not limited to: a data center storage system, a power grid, or a micro-grid. A stationary energy system can be used in either a storage or non-storage role.

(51) In describing embodiments herein, reference may be made to a particular mobile application (e.g., an electric vehicle (EV)) or stationary application (e.g., grid). Such references are made for ease of explanation and do not mean that a particular embodiment is limited for use to only that particular mobile or stationary application. Embodiments of systems providing power to a motor can be used in both mobile and stationary applications. While certain configurations may be more suitable to some applications over others, all example embodiments disclosed herein are capable of use in both mobile and stationary applications unless otherwise noted.

Example Embodiments of Module-Based Energy Systems

(52) FIG. **1**A depicts an example embodiment of a module-based energy system **100**. Here, system **100** includes control circuitry **102** communicatively coupled with N converter-source modules **108**-

1 through **108**-N, over communication paths or links **106-1** through **106**-N, respectively. In these embodiments, any number of two or more converter-source modules **108** can be used (e.g., N is greater than or equal to two). The converter-source modules **108**, referred to herein as "ConSource" modules or modules **108**, can be connected to each other in a variety of manners as will be described in more detail with respect to FIGS. **15-29**. For ease of illustration, in FIGS. **1**A-**1**C, modules **108** are shown connected in series, or as a one dimensional array, where the Nth module **108** is coupled to a load **101**. Load **101** is the electrical load to which system **100** outputs power when used to provide power. Load **101** can be any type of load including, but not limited to, a motor or a grid. For charging, modules **108** can be coupled with a charging source (not shown) either in addition to, or instead of, load **101**. As will be described in greater detail herein, system **100** can be configured to supply multiple loads **101**, including both primary and auxiliary loads.

(53) In the embodiment of FIG. **1**A, control circuitry **102** is configured to control one or more modules **108** based on status information received from the same or different one or more of the modules **108**. Control can also be based on one or more other factors, such as requirements of load **101**. In many embodiments, the aspect that is controlled is the output power of each module **108** over time; however other aspects can be controlled as an alternative to or in addition to output power.

(54) Load requirement information **109** can be received by control circuitry **102** over a communication path or link **107**. Load requirement information **109** can inform control circuitry **102** as to the requirements of load **101** at any particular time. In some example embodiments, the load requirement information **109** can take the form of one or more analog or digital control signal waveforms (e.g., a different control signal waveform for each phase), such as can be provided by a controller for a mobile entity (e.g., an Electronic Control Unit (ECU) or Master Control Unit (MCU) having responsibility for one or more other functions (e.g., motor control, driver interface control, traction control, etc.) of an EV) or controller for a grid or other stationary energy storage system. As an alternative to, or in addition to the information supplied by another controller, in some embodiments the load requirement information **109** can include load measurements (e.g., voltage, current) taken by one or more sensors of system **100**, where those measurements are supplied back to control circuitry **102** in a feedback loop for maintaining certain power supply conditions.

(55) In many embodiments, status information of every module **108** in system **100** will be communicated to control circuitry **102**, from which control circuitry **102** will independently control every module **108-1** . . . **108**-N. Other variations are possible. For example, control of a particular module **108** (or subset of modules **108**) can be based on status information of that particular module **108** (or subset of ConSource modules **108**), based on status information of a different module **108** that is not the particular module **108** (or subset of modules **108**), based on status information of all modules **108** other than the particular module **108** (or subset of modules **108**), based on status information of that particular module **108** (or subset of modules **108**) and status information of at least one other module **108** that is not that particular module **108** (or subset of modules **108**), or based on status information of all modules **108** in system **100**. This includes a system **100** supplying multiple loads or motors, and having modules **108** arranged in multiple packs.

(56) As will be described herein, the status information can be information about one or more aspects of each module **108**. The status information can be an operating characteristic or other parameter. Types of status information include, but are not limited to, the following aspects of a module **108** or components thereof: State of Charge (SOC) (e.g., the level of charge of an energy source relative to its capacity, such as a fraction or percent), State of Health (SOH) (e.g., a figure of merit of the condition of an energy source compared to its ideal conditions), capacity (Q), temperature (T), voltage (V), current (I), or the presence of absence of a fault. Each module **108** includes one or more sensors or other measuring elements for collecting sensed or measured signals

or data that constitute status information, or can be converted into status information. A separate sensor is not needed to collect each type of status information, as more than one type of status information can be sensed or measured with a single sensor, or otherwise algorithmically determined without the need for additional sensors.

(57) FIG. **1**B depicts another example embodiment of system **100**. Here, control circuitry **102** is implemented as a master control device **112** communicatively coupled with N different local control devices **114-1** through **114**-N over communication paths or links **115-1** through **115**-N, respectively. Each local control device **114-1** through **114**-N is communicatively coupled with one converter-source module **108-1** through **108**-N over communication paths or links **116-1** through **116**-N, respectively, such that there is a 1:1 relationship between local control devices **114** and converter-source modules **108**. Master control device **112** can be communicatively coupled to all local control devices **114** in the system, regardless of whether those local control device **114** are supplying power to the same load. For example, one master control device **112** can receive and send information to local control devices **114** of multiple different subsystems and packs.

(58) FIG. **1**C depicts another example embodiment of system **100**. Here, master control device **112** is communicatively coupled with M different local control devices **114-1** through **114**-M over communication paths or links **115-1** through **115**-M, respectively. Local control devices **114** can be coupled with and control two or more converter-source modules **108**. In the example shown here, each local control device **114** is communicatively coupled with two converter-source modules **108**, such that M local control devices **114-1** through **114**-M are coupled with **2M** converter-source modules **108-1** through **108**-2M over communication paths or links **116-1** through **116**-2M, respectively.

(59) Communication paths or links **106**, **107**, **115**, and **116** can each be wired or wireless communication paths or links that communicate data or information bidirectionally, in parallel or series fashion. Data can be communicated in a standard or custom format. In some (e.g., automotive) applications, communication paths or links **115** can be configured to communicate data according to FlexRay or CAN protocols.

(60) In the embodiments described with respect to FIGS. **1**B and **1**C, the local control devices **114** receive the status information from each module **108**, or determine the status information from sensed or measured signals or data received from each module **108**, and communicate that information to master control device **112**. In some embodiments local control devices **114** communicate the measured or sensed data to master control device **112**, which then algorithmically determines the status information on the basis of that raw data. Master control device **112** can then use the status information about all of the modules **108** to make control determinations accordingly. The control determinations may take the form of instructions, commands, or other information (such as a modulation index described below) that can be interpreted or utilized by local control devices **114** to either maintain or adjust the operation or contribution of the modules **108**.

(61) For example, with respect to SOC, if upon reading the SOC measurements for all modules **108**, master control device **112** makes an assessment that a first module **108** is operating at a relatively lower SOC than other modules **108** supplying power for a phase of system **100**, then master control device **112** can instruct that first module **108** to decrease its power output, and can instruct one or more other modules **108** to increase power output(s) in that phase to compensate. This should cause the SOC of the other modules **108** to decrease faster than that of the first module **108**, and thus converge to a balanced condition. With respect to temperature, if upon reading temperature measurements for all modules **108**, master control device **112** makes an assessment that a first module **108** is operating at a relatively higher temperature than other modules **108** supplying power for a phase in system **100**, then master control device **112** can instruct that first module **108** to decrease its power output, and can instruct one or more other modules **108** to increase power output(s) in that phase to compensate. This should cause the temperature of the first module **108** to approach that of the other modules **108** (by cooling of the first module **108** and/or

heating of the other modules **108**), and thus converge to a balanced condition.

(62) Master control device **112** may receive status information indicating one or more of the following conditions that a particular module **108** (or component thereof) is operating in with respect to one or more other modules **108** in system **100**: with a relatively lower SOC, with a relatively lower SOH, with a relatively lower capacity, with a relatively lower voltage, with a relatively lower current, with a relatively higher temperature, or with a fault. In such an example, master control device **112** can output control information that causes the power output of that particular module **108** to be reduced (or in some cases, raised depending on the condition). In this manner, the power output of a module **108** that is operating with, e.g., a higher temperature, can be reduced so as to cause the temperature of that module **108** to converge towards the temperature of one or more other modules **108**.

(63) In other embodiments, the determination of whether to adjust the operation of a particular module **108** can be made by comparison of the status information to predetermined thresholds, limits, or conditions, and not necessarily by comparison to statuses of other modules **108**. The predetermined thresholds, limits, or conditions can be static thresholds, limits, or conditions, such as those set by the manufacturer that do not change during use. The predetermined thresholds, limits, or conditions can be dynamic thresholds, limits, or conditions, that are permitted to change, or that do change, during use. For example, master control device **112** can adjust the operation of a module **108** if the status information for that module **108** indicates it to be operating in violation (e.g., above or below) of a predetermined threshold or limit, or outside of a predetermined range of acceptable operating conditions. Similarly, master control device **112** can adjust the operation of a module **108** if the status information for that module **108** indicates the presence of an actual or potential fault (e.g., an alarm, or warning) or indicates the absence or removal of an actual or potential fault. Examples of a fault include, but are not limited to, an actual failure of a component, a potential failure of a component, a short circuit or other excessive current condition, an open circuit, an excessive voltage condition, a failure to receive a communication, the receipt of corrupted data, and the like.

(64) Local control device **114** can receive, process, and transmit: the signals from various sensors (e.g., temperature, voltage and current sensors) of the module **108**; switching (e.g., triggering) and fault signals to and from semiconductor switches; the voltages of elementary cells of energy storage and buffering elements; and other signals. The local control device **114** can perform communication with and transmission of corresponding control signals to and from the master control device **112**.

(65) In this manner, master control device **112** can control the modules **108** within system **100** to achieve or converge towards a desired target. The target can be, for example, operation of all modules **108** at the same or similar levels with respect to each other, or within predetermined thresholds limits, or conditions. This process is also referred to as balancing or seeking to achieve balance in the operation or operating characteristics of the modules **108**. The term "balance" as used herein does not require absolute equality between modules **108** or components thereof, but rather is used in a broad sense to convey to those of ordinary skill in the art that operation of system **100** can be used to actively reduce disparities in operation between modules **108** that would otherwise exist.

(66) Referring back to FIG. **1**A, control circuitry **102** can be configured to operate and execute control using software (instructions stored in memory that are executable by processing circuitry), hardware, or a combination thereof. Control circuitry **102** can include processing circuitry **120** and memory **122** as shown here. Example implementations of processing circuitry **120** and memory **122** are described further below. Communication path or links **106** can also include wireline power so as to directly supply the operating power for control circuitry **102** from one or more converter source modules **108**. In certain embodiments power for control circuitry **102** is supplied from only one or more modules **108**.

(67) Referring to FIGS. **1**B-**1**C, master control device **112** and local control devices **114** can similarly be configured to operate and execute control using software (instructions stored in memory that are executable by processing circuitry), hardware, or a combination thereof, and each can include processing circuitry **120** and memory **122** as shown here. Example implementations of processing circuitry **120** and memory **122** are described further below. Communication path or links **116** can also include wireline power so as to directly supply the operating power for local control devices **114** from one or more modules **108**. In certain embodiments, the operating power for each local control device **114** is supplied only by the one or more modules **108** to which that local control device **114** is connected by path **116**. The operating power for the master control device **112** can be supplied indirectly from one or more of the modules **108** (e.g., such as through a car's power network).

(68) In some embodiments, control circuitry **102** can include a single control device for the entire system **100**. In other embodiments, control circuitry can be distributed between local control devices **114** associated with the modules **108**, such that a separate master control device **112** is not necessary and can be omitted from system **100**.

(69) In some embodiments, control of system **100** can be distributed between control circuitry **102** dedicated to or local to system **100**, and control circuitry that is shared with other parts of the application. For example, master control device **112** can be implemented as part of a mobile or stationary controller providing load requirement information **109** to system **100** (e.g., ECU or MCU). Control circuitry **102** can have a communicative interface for communicating with another control device of the overall mobile or stationary application. For example, in an automotive application, control circuitry **102** (e.g., master control device **112**) can output data or information about system **100** to the ECU or MCU of the vehicle.

Example Embodiments of Converter-Source Modules within Module-Based Systems

(70) FIGS. **2**-**4** depict example embodiments of converter-source modules **108** within system **100** as depicted in FIG. **1**B, with one local control device **114** per module **108**. The embodiments of FIGS. **2**-**4** and any and all other embodiments described herein can be implemented in accordance with the configurations of FIGS. **1**A-**1**C unless otherwise noted.

(71) ConSource modules **108** can be implemented as voltage converters or current converters. For ease of description, the embodiments described herein are done so with reference to voltage converters, although the embodiments can alternatively be configured as current converters.

(72) FIG. **2** is a block diagram depicting an example embodiment of a ConSource module **108**A within system **100**. This embodiment of ConSource module **108**A may be referred to herein as version **1** of an example ConSource module (ConSource V**1**) and is an example of a type of converter-source module **108**. Also shown is a local control device **114** (LCD) and a master control device **112** (MCD). ConSource V**1** **108**A is communicatively coupled with the LCD **114**, which in turn is communicatively coupled with the MCD **112**.

(73) The ConSource V**1** **108**A includes an energy source **202** (Energy Source **1**), which can include one or more energy storage elements. Energy Source **1** can be, for example, one of the following, but not limited to, a high energy density (HED) capacitor such as an ultra-capacitor or a supercapacitor **600** (FIG. **6**A), a battery module **610** including at least one cell or multiple battery cells connected in series and/or in parallel (FIG. **6**B), or fuel, a fuel-cell, or fuel cell module **620** (FIG. **6**C). HED capacitor **600** can utilize a double layer capacitance as opposed to a solid dielectric, and can have an energy density of 10 to 100 times (or higher) that of an ordinary electrolytic capacitor, in addition to a higher capacity. Battery energy sources

(74) Energy can be input and output through a first node (e.g., a positive node) out**1** and a second node (e.g., a negative node) out**2**. The outputs out**1** and out**2** of Energy Source **1** can be connected to input terminals in**1** and in**2** of an Energy Buffer **204**, respectively, which can include, for example, one of the following, but not limited to, elements and topologies based on: an electrolytic and/or film capacitor CEB **700** (FIG. **7**A), a Z-source network **710**, formed by two inductors LEB**1**

and LEB2 and two electrolytic and/or film capacitors CEB1 and CEB2 (FIG. 7B), a Quasi Z-source network **720**, formed by two inductors LEB1 and LEB2, two electrolytic and/or film capacitors CEB1 and CEB2 and a diode DEB (FIG. **7**C). A choice of specific topology and components of Energy Buffer depends on a maximum permissible amplitude of high frequency voltage pulsations on output terminals out**1** and out **2** of the Energy Buffer. These pulsations can degrade the performance of the ConSource module **108**, thus they can be efficiently buffered by designing suitable elements and topologies as a basis thereof.

(75) The outputs out**1** and out**2** of Energy Buffer **204** are connected respectively to the inputs in**1** and in**2** of a Converter V**1**. A schematic representation of an example embodiment of a converter V**1** **206** is shown in FIG. **5**A. The Converter V**1** **206** can include switch circuitry **207** configured to place at least three different voltages (based on line voltage V.sub.DCL) across out**1** and out**2**: +V.sub.DCL, −V.sub.DCL, and zero (e.g., a short condition). Switch circuitry **207** can also be configured to block current flow across out**1** and out**2** (e.g., an open condition). Switch circuitry **207** can be configured in numerous different ways within numerous different switch types. Example switch types include, but are not limited to semiconductor switches, such as metal-oxide-semiconductor field-effect transistors or MOSFETs (as shown in FIG. **5**A), insulated-gate bipolar transistors (IGBTs) or Gallium Nitride (GaN) transistors. Semiconductor switches can be operated at relatively high switching frequencies, thereby permitting the Converter V**1** to be operated in pulse-width modulated mode if desired, and to respond to control commands within a relatively short interval of time. This can provide a high tolerance of output voltage regulation and fast dynamic behavior in transient modes. The switch circuitry **207** can be controlled by one or more control or switch signals (not shown) produced by control circuitry **102** (e.g., MCD **112** or LCD **114**).

(76) In many embodiments, the switch circuitry **207** can include at least four independently controllable switches S**3**, S**4**, S**5**, S**6**, which can be configured as an H-bridge. In this embodiment, Converter V**1** **206** generates three different voltage outputs, +V.sub.DCL, 0, and −V.sub.DCL by connecting the DC line voltage V.sub.DCL, between its terminals in**1** and in**2**, to its output terminals out**1** and out**2** by different combinations of switches S**3**, S**4**, S**5**, S**6**. To obtain +V.sub.DCL, switches S**3** and S**6** are turned on, whereas −V.sub.DCL can be obtained by turning on the switches S**4** and S**5**. By turning on S**3** and S**5** or S**4** and S**6**, the output voltage is set to zero (e.g., short) or a reference voltage.

(77) The control or switch signals (input paths not shown) for semiconductor switches S**3**, S**4**, S**5**, S**6** may be generated in different ways depending on the flexibility and requirements of the adopted control technique in the LCD and MCD (shown in FIG. **2**). One approach is to use pulse width modulation (PWM) techniques, such as space vector pulse-width modulation SVPWM or sinusoidal pulse-width modulation SPWM, or variations thereof, to generate the output voltage of Converter V**1**. An example of an output voltage waveform **900** of a Converter V**1** is shown in FIG. **9**. The modulation method also depends on which version of system **100** to which it is applied and one possible solution of modulation will be presented herein further as an example.

(78) In some embodiments using PWM, the LCD (and not the MCD) generates the switching signals for the switches in the ConSource module, although the PWM embodiments are not limited to such. In some embodiments, such as those using hysteresis, generation of the switching signals can be performed by the MCD. The LCD **114** shown in FIG. **2** can be connected to ConSource V**1** **108**A via a set of diagnostics, measurement, protection and control signal lines, and can perform one or more of three primary functions. The first function is management of Energy Source **1**. The second function is protection of the Energy Buffer and more specifically its components from over-current, over-voltage and high temperature conditions. The third function is control and protection of Converter V**1** **206**.

(79) In one example embodiment, the function of management, by the LCD **114**, of Energy Source **1** for ConSource V**1** module **108**A is as follows. The LCD **114** accepts the measurement signals

VES**1**, TES**1**, IES**1**, which are: VES**1**—the voltages of at least one of the, preferably all, elementary components of Energy Source **1** or the voltages of groups of elementary components, such as, for example and not limited to, battery cells (individual or connected in series and/or in parallel), ultra-capacitor cells (individual, or connected in series and/or in parallel); TES**1**—the temperatures of at least one of, preferably all, elementary components of Energy Source **1** or the temperatures of groups of elementary components; IES**1**—the output current of Energy Source **1**. Based on these measurement signals the LCD **114** can perform one or more of the following: calculation or determination of a real capacity, actual State of Charge (SOC) and State of Health (SOH) of the elementary components or groups of elementary components; set a warning or alarm signal, based on measured and/or calculated data; and/or transmission of corresponding signals to the MCD **112**.

(80) In one example embodiment, the function of protection, by the LCD, of the Energy Buffer **204** for ConSource V**1** module **108**A is as follows. The LCD **114** accepts the measurement signals VEB, TEB, IEB, which are: VEB—the voltages of at least one major component of the Energy Buffer **204**, for example and not limited to, capacitor CEB, or capacitors CEB**1**, CEB**2** (see FIGS. **7**A-**7**C); TEB—the temperature of at least one component of the Energy Buffer **204**; and/or IEB—the current through at least one component of the Energy Buffer **204**. Based on these measurement signals, the LCD **114** can perform the following: setting of a warning or alarm signal based on measured data; and/or transmission of corresponding warning or alarm signals to the MCD **112**.

(81) In one example embodiment, the function of control and protection, by the LCD **114**, of the Converter V**1** **206** for ConSource V**1** module **108**A is as follows. The LCD can receive the command signals from the MCD over path **115** (e.g., over FlexRay or CAN), which in some embodiments can be a modulation reference signal and an enable signal, or a reference signal and a modulation index, which can be used with a pulse width modulation technique in the LCD to generate the control signals for semiconductor switches S**3**, S**4**, S**5**, S**6**. The current feedback signal TOUT (not shown in FIG. **2**) coming from an integrated current sensor of Converter V**1** **206** can be used for overcurrent protection together with one or more signals F, coming from driver circuits (not shown in FIG. **2**) of the switches of Converter V**1** **206**, which can carry information about failure statuses (e.g., short circuit or open circuit failure modes) of all switches in Converter V**1**. Based on this data, the LCD can make a decision on which combination of switching signals to be applied to corresponding semiconductor switches S**3**, S**4**, S**5**, S**6** to bypass or to disconnect the Converter V**1** and the entire ConSource V**1** module **108**A from system **100**. (A switching signals for a particular switch can turn that switch on or off.)

(82) FIG. **3** is a block diagram depicting another example embodiment of a ConSource module **108**B that may be referred to herein as version **2** of the ConSource module (ConSource V**2**) and is an example of a type of converter-source module **108**. ConSource V**2** **108**B is communicatively coupled with the LCD **114**, which in turn is communicatively coupled with the MCD **112**.

(83) In this embodiment, the ConSource V**2** **108**B is in a dual energy source configuration with a primary Energy Source **1** **202** and secondary Energy Source **2** **304**. As with the ConSource V**1** **108**A, Energy Source **1** can be or include any of the examples described with respect to FIGS. **6**A-**6**C, or others.

(84) The outputs out**1** and out**2** of Energy Source **1** **202** can be connected to input terminals in**1** and in**2** of Energy Buffer **204**. As with the ConSource V**1** **108**A, Energy Buffer **204** can be or include any of the examples described with respect to FIGS. **7**A-**7**C, or others. The outputs out**1** and out**2** of Energy Buffer **204** are connected respectively to the inputs in**1** and in**3** of Converter V**2** **308**.

(85) The output out**2** of the Energy Buffer **204** can be connected also to the output out**2** of Energy Source **2** **304**. Another output of Energy Source **2**, out**1**, can be connected to input in**2** of Converter V**2** **308**. The Energy Source **2** can include, for example, one of the following, but not limited to, storage elements such as: an electrolytic and/or a film capacitor CEB **800** (FIG. **8**A); a high energy density (HED) capacitor **600** (FIG. **8**B); a battery or battery module **610** including at least one

battery cell or plurality of battery cells connected in series and/or in parallel (FIG. **8**C); an electrolytic and/or a film capacitor CEB **800** connected in parallel with a high energy density capacitor **600** (FIG. **8**D); an electrolytic and/or a film capacitor CEB **800** connected in parallel with battery module **610** (FIG. **8**E); an electrolytic and/or a film capacitor CEB **800** connected in parallel with a high energy density capacitor **600** and a battery module **610** (FIG. **8**F).

(86) A simplified schematic representation of example embodiment of a Converter V**2 308** is shown in FIG. **5**B. Here, the Converter V**2 308** includes switch circuitry **207** (as described with respect to FIG. **5**A) and switch circuitry **208**. Switch circuitry **208** can be configured in any arrangement and with any switch type that selectively couple in**2** (through L.sub.C) to either in**1** or in**3**. Switch circuitry **208** can also be configured to block current flow through in**2** (i.e., isolate in**2**) from in**1** and in**3**. Switch circuitry **208** can be configured in any of the switch types described herein (e.g., semiconductor MOSFETs, IGBTs, GaN transistors, or others). Semiconductor switches can be operated at high switching frequency, thereby permitting the Converter V**2 308** to be operated in pulse-width modulated mode if required, and to respond to the control commands within a short interval of time, providing a high tolerance of output voltages regulation and fast dynamic behavior in transient modes.

(87) In this embodiment, switch circuitry **208** includes two independently controllable switches S**1** and S**2**, and can generate two different voltages at Node **1**, which are +VDCL and 0, referenced to input In**3**, which can be at virtual zero potential. The coupling inductor L.sub.C is connected between input In**2** and Node **1**. The output out**1** of Energy Source **2** is connected to coupling inductor L.sub.C at the input In **3** of Converter V**2 308**. The current consumed from or generated to Energy Source **2 304** can be controlled by regulating the voltage on coupling inductor L.sub.C, using, for example, a pulse-width modulation technique or a hysteresis control method for commutating switches S**1** and S**2**. Other techniques can be used as well. Control signal input paths for switches S**1** and S**2** are not shown.

(88) In this embodiment, switch circuitry **207** is configured in a similar manner as shown in FIG. **5**A, and includes four switches S**3**, S**4**, S**5**, S**6** capable of generating three different voltage outputs, +V.sub.DCL, 0 (or a short condition), and −V.sub.DCL by connecting the DC line voltage V.sub.DCL between terminals in**1** and in**2** to the output terminals out**1** and out**2** by different combinations of switches S**3**, S**4**, S**5**, S**6**. To obtain +V.sub.DCL voltage between out**1** and out**2**, switches S**3** and S**6** are turned on, whereas −V.sub.DCL voltage between out**1** and out**2** can be obtained by turning on switches S**4** and S**5**. By turning on S**3** and S**5** or S**4** and S**6**, the output voltage is set to zero or a reference potential. As with semiconductor switches S**1** and S**2**, the control of semiconductor switches S**3**, S**4**, S**5**, S**6** may be performed using the various PWM or hysteresis techniques described herein, or others. Control signal input paths for switches S**3**, S**4**, S**5**, S**6** are not shown.

(89) In this example ConSource V**2** module **108**B, Energy Source **1 202** acts as a primary energy source and therefore supplies the average power needed by the load. Energy Source **2 304** can be a secondary energy source with the function of assisting Energy Source **1** by providing additional power at load power peaks, or absorbing excess power.

(90) FIG. **10** shows the output voltage waveform **1000** from an example module-based energy storage system having six example converter-source modules **108**.

(91) FIG. **11** is a block diagram depicting an example embodiment of power flow management **1100** between two Energy Sources (Energy Source **1 202** and Energy Source **2 304**) and a load for an example embodiment of a ConSource V**2** module **108**B. The load can be, for example, but not limited to, a single phase of an electric vehicle motor or an electrical grid. This embodiment allows a complete decoupling between the electrical characteristics (terminal voltage and current) of each energy source and those of the load **1102**.

(92) In these embodiments, Power Flow Controller **1 1110** and Power Flow Controller **2 1120** can be discrete control devices, separate from the LCD **114** and MCD **112**, can be implemented as

software within the LCD, can be implemented as hardware within the LCD, or can be implemented as a combination of hardware and software within the LCD. In some embodiments, the functions of Power Flow Controller **1 1110** and Power Flow Controller **2 1120** can be shared or distributed between the LCD **114** and MCD **112**.

(93) Power Flow Controller **1 1110** can receive a signal of reference power flow of Energy Source **1** (P.sub.ES1, REF) from the LCD **114**. This signal can be determined by a main Power Management Controller located in the MCD **112** based on motor power or electrical grid power requirements and a status of Energy Source **1 202** of the ConSource V**2** module **108**B. Power Flow Controller **1 1110** can estimate a maximum allowable charge and/or discharge current of Energy Source **1 202** and calculate a real permissible power flow (P E si) of Energy Source **1**. This value can be compared with P.sub.CONSOURCE and the difference can be applied to Power Flow Controller **2 1120** as a signal (P.sub.ES2, REF). Power Flow Controller **2 1120** can calculate the reference current in coupling inductor L.sub.C based on the voltage between output terminals out**1** and out**2** of Energy Source **2 304** and determines the switching signals for switches S**1** and S**2** of Converter V**2 308**, using, for example, but not limited to pulse-width modulation or hysteresis control algorithms. Thus, the total power flow (P.sub.CONSOURCE) can be provided by the switching portion of Converter V**2** that includes switches S**3**, S**4**, S**5**, S**6**. The power flow of Energy Source **1 202** (P E si) can be estimated based on a maximum permissible current of Energy Source **1** and actual conditions of Energy Source **1**, such as, but not limited to, State of Charge (SOC), State of Health (SOH), temperature of elementary cells or a group of parallel and/or series connected cells, equivalent series resistance, and the like. The power flow (P.sub.ES1) can be maintained as a difference between current values of the load (P.sub.LOAD) and energy source **2** (P.sub.ES2), where P.sub.ES2 is managed by the switching portion of Converter V**2 308** that includes switches S**1**, S**2** and the coupling inductor L.sub.C.

(94) In many embodiments, Energy Source **2 304** can be a secondary energy source and its function is to assist Energy Source **1 202** by providing power at load power peaks and/or absorbing excess power. A secondary function of Energy Source **2 304** can be active filtering, such as to reduce (attenuate) or eliminate any second-order current harmonic that appears in the current IDC_CONV flowing at the inputs in**1** and in**3** of the Converter V**2** as a result of, e.g., the intrinsic pulsating power nature of a single-phase system. This harmonic can have a considerable peak-to-peak value, which can reach up to two times the load current amplitude. The second-order current component exhibits some disadvantages, e.g., increase of the inner losses in the Energy Source **1 202** related to the resulting current RMS value. To perform this secondary function, Energy Source **2 304** can include an electrolytic capacitor or an ultra-capacitor (or super-capacitor) as standalone components, or connected in parallel with other energy storage elements as shown in FIGS. **8**A, **8**B, and **8**D-**8**F.

(95) FIGS. **12**A and **12**B show examples of waveforms **1200**, **1220** occurring before and during performance this active filtering secondary function. Before the compensations starts (before time moment t.sub.1), the current of Energy Source **1 202** (FIG. **12**A) includes a DC-component (IDC=130 A) and a second order harmonic component with an amplitude I2 AC=60 A. The high frequency harmonics (not shown) that are determined by the switching behavior of Converter V**2 308** are efficiently buffered by the Energy Buffer **204**. Starting from the time moment t.sub.1, the Converter V**2** starts generating current I.sub.ES2, redirecting the second order harmonic of current I.sub.ES1 to Energy Source **2**. This current I.sub.ES2 has an amplitude of main harmonic equal to that of the second order harmonic of I.sub.ES1 current, but with nearly opposite phase angle, in such a way that the resulting current in Energy Source **1** I.sub.ES1 includes either DC-component only or mostly DC-component with some significantly reduced AC-ripples, as shown in FIG. **12**A. In a case where only the secondary function is performed by Converter V**2**, and if the Energy Source **2** includes only a capacitor and/or a super-capacitor **810**, the current I.sub.ES2 (FIG. **12**B) may include a DC component which is needed to be supplied from the load or from Energy Source

1 202 to maintain the voltage on the capacitor and/or the super-capacitor **810** of Energy Source **2 304** at set value, which is required for correct operation of Converter V**2 308**.

(96) Both primary and secondary functions performed by Converter V**2** and described above can be performed either separately or at the same time. If at the same time, the Energy Source **2 304** preferably includes an electrolytic capacitor or ultra-capacitor **810** connected in parallel with other energy storage elements as shown in FIGS. **8**A, **8**B, and **8**D-**8**F.

(97) The LCD **114** for ConSource V**2** module is shown in FIG. **3** connected to ConSource V**2** module **108**B via a set of diagnostics, measurement, protection and control signal lines, and can perform at least one of, preferably all of, four major functions. The first function is management of Energy Source **1 202**. The second function is management of Energy Source **2 304**. The third function is protection of the Energy Buffer **204** and more specifically its components from over-current, over-voltage and high temperature. The fourth function is control and protection of Converter V**2 308**.

(98) The function of management of Energy Source **1** for ConSource V**2** module **108**B can be as follows. The LCD **114** accepts the measurement signals VES**1**, TES**1**, IES**1**, which are: VES**1**—the voltages of all elementary components/cells of Energy Source **1** or the voltages of groups of elementary components/cells, such as, for example, but not limited to, battery cells, individual or connected in series and/or in parallel, ultra-capacitor cells, individual, or connected in series and/or in parallel; TES**1**—the temperatures of all elementary components of Energy Source **1** or the temperatures of groups of elementary components; IES**1**—the output current of Energy Source **1**. Based on these measurement signals LCD can perform the following: calculates a real capacity, actual State of Charge (SOC) and State of Health (SOH) of the elementary components or groups of elementary components; set a warning or alarm signal based on measured and calculated data; transmission of corresponding signals to the MCD **112**.

(99) The function of management of Energy Source **2 304** for ConSource V**2** module **108**B can be as follows. The LCD **114** can receive the measurement signals VES**2**, TES**2**, IES**2**, which are: VES**2**—the voltages of all elementary components or cells of Energy Source **2** or the voltages of groups of elementary components or cells, such as, for example and not limited to, battery cells, individually or connected in series and/or in parallel, ultra-capacitor cells, individually or connected in series and/or in parallel; TES**2**—the temperatures of all elementary components of Energy Source **2** or the temperatures of groups of elementary components; IES**2**—the output current of Energy Source **2**. Based on these measurement signals, the LCD can perform the following: calculates a real capacity, actual State of Charge (SOC) and State of Health (SOH) of the elementary components or groups of elementary components; set a warning or alarm signal, based on measured and calculated data; and/or communicated corresponding signals to the MCD.

(100) The function of protection of Energy Buffer **204** for ConSource V**2** module **108**B can be as follows. The LCD **114** receives the measurement signals VEB, TEB, IEB, which are: VEB—the voltages of at least one major component of Energy Buffer, for example and not limited to, capacitor CEB, or capacitors CEB**1**, CEB**2** (see FIGS. **7**A-**7**C); TEB—the temperature of at least one major components of Energy Buffer; and/or IEB—the current through at least one major components of Energy Buffer. Based on these measurement signals LCD can perform the following: set a fault (e.g., warning or alarm) signal based on measured data; and/or transmit corresponding fault signals to the MCD **112**.

(101) The function of control and protection of Converter V**2 308** for ConSource V**2** module **108**B can be as follows. The LCD **114** receives the command signals from the MCD **112**, which can be a modulation reference signal and enable signal, or a reference signal and a modulation index, which can be used in a PWM and/or a Hysteresis function in the LCD to generate the control signals for semiconductor switches S**1**, S**2**, S**3**, S**4**, S**5**, S**6** in accordance to power management and/or second order harmonic reduction techniques described above. The current feedback signals IES**2**, TOUT coming from the integrated current sensors (not shown in FIG. **3**) of Converter V**2** can be used for

overcurrent protection together with signals F, for example, coming from driver circuits (not shown in FIG. **3**), of semiconductor devices of Converter V**2 308**, which carry the information about failure statuses (e.g., short circuit or open circuit failure mode) of one or more, preferably all, of the semiconductor switches. Based on this specific data, the LCD **114** can make a decision on which combination of switching signals S**1**, S**2**, S**3**, S**4**, S**5**, S**6** to be applied to the corresponding semiconductor switches to bypass or disconnect the Converter V**2** and the entire ConSource V**2** module from system **100** (e.g., the battery pack, etc.).

(102) FIG. **4** is a block diagram depicting an example embodiment of a ConSource module **108**C, referred to as version **3** of the ConSource module (ConSource V**3**) and is an example of a type of converter-source module **108**. ConSource V**3 108**C is communicatively coupled with the LCD **114**, which in turn is communicatively coupled with the MCD **114**.

(103) The ConSource V**3** module **108**C can include an energy source Energy Source **1 202** and Converter V**2 308** with an additional input for connection of an Auxiliary Load **2 410**, if desired. The ConSource V**3** module has output ports **1** and **2** for connection with other ConSource (e.g., V**1**/V**2**/V**3**) modules within an example system **100**. The illustrated output ports **3** and **4** of ConSource V**3** are used for connection of the example ConSource V**3** module to the same output ports of other ConSource V**3** modules of an example system **100**, if needed, and/or for connection to an Auxiliary Load **1 408**, if desired. The illustrated output ports **5** and **6** of ConSource V**3 108**C are used for connection of the example ConSource V**3** module to the same output ports of other ConSource V**3** modules of an example system **100**, if needed, and/or for connection to an Auxiliary Load **2 410**, if desired.

(104) As with the ConSource V**1 108**A, Energy Source **1 202** of ConSource V**3** module **108**C can be or include any of the examples described with respect to FIGS. **6**A-**6**C, or others.

(105) The outputs out**1** and out**2** of Energy Source **1 202** are connected to input terminals in**1** and in**2** of the Energy Buffer **204**. As with the ConSource V**1 108**A, Energy Buffer **204** of ConSource V**3** module **108**C can be or include any of the examples described with respect to FIGS. **7**A-**7**C, or others.

(106) The outputs out**1** and out**2** of Energy Buffer **204** are connected respectively to the inputs in**1** and in**3** of Converter V**2 308**. Converter V**2 308** can be configured as discussed with respect to ConSource V**2** module **108**B (e.g., with respect to FIG. **5**B). In this embodiment, the output of coupling inductor L.sub.C is connected through input In**2** of Converter V**2 308** to port **5** of ConSource V**3** module **108**C and to optional Auxiliary Load **2 410** as shown in FIG. **4**. It is assumed that Auxiliary Load **2** has an input capacitor, so the Converter V**2 308** can regulate, step down, and stabilize the required constant voltage on the load regulating the voltage on and current through coupling inductor L.sub.C. If no input capacitor is present, then an optional capacitor (not shown) can be placed between In**2** and In**3** (or node **1** and in**3**) to form an L.sub.C circuit with coupling inductor L.sub.C. For example, if Energy Source **1** is a battery module with a 48V standard operating voltage (e.g., twelve 4V cells in series), and Auxiliary Load **2** requires 24V, then S**1** and S**2** can be controlled to operate with a 50% duty cycle (with S**1** closed and S**2** open, then with S**1** open and S**2** closed) and, based on feedback from a current and/or voltage sensor, adjusted accordingly to maintain the voltage at the lower stepped down level of 24V. Auxiliary Load **1** is coupled in parallel with Energy Source **1**, and thus operates at the same voltage as Energy Source **1** without regulation by Converter V**2 308**.

(107) Additional auxiliary loads (e.g., Auxiliary Load **1**) can be supplied by coupling outputs **3** and **4** to other loads operating at the same voltage as Energy Source **1**, or alternatively by providing additional instances of outputs **3** and **4** for those additional loads. Additional auxiliary loads operating at stepped down voltages from Energy Source **1** (e.g., Auxiliary Load **2**) can be supplied by adding additional instances of switch circuitry **208** and coupling inductor L.sub.C, with additional output ports **5** and **6**. Thus, the modules **108** described herein can be configured to supply any number of one or more auxiliary loads operating at the same or lower voltage levels

than Energy Source **1**.

(108) The control switching signals for semiconductor switches S**3**, S**4**, S**5**, S**6** may be generated in different ways depending on the flexibility and requirements of the adopted control technique in the LCD **114** and the MCD **112**.

(109) Energy Source **1 202** can supply the corresponding part of power needed by the load of system **100**, Auxiliary Load **1 408** and/or Auxiliary Load **2 410**, if connected. FIG. **13** shows an example of power flow management for a ConSource V**3** module, where power flow between Energy Source **1**, Auxiliary Load **1**, and Auxiliary Load **2** can be adjusted. Examples of auxiliary loads can be, for example, an on-board electrical network of an electric vehicle, an HVAC system of an electric vehicle. The load of system **100** can be, for example, one of the phases of the electric vehicle motor or electrical grid. This embodiment can allow a complete decoupling between the electrical characteristics (terminal voltage and current) of the energy source and those of the loads.

(110) In these embodiments, referring to FIG. **13**, Power Flow Controller **1 1310** (PFC **1**), Power Flow Controller **2 1320** (PFC **2**), Power Flow Estimator **1** (PFE **1**), and Power Flow Estimator **2** (PFE **2**) can be discrete control devices, separate from the LCD **114** and MCD **112**, can be implemented as software within the LCD, can be implemented as hardware within the LCD, or can be implemented as a combination of hardware and software within the LCD. In some embodiments, the functions of PFC **1**, PFC **2**, PFE **1**, and PFE **2** can be shared or distributed between the LCD and MCD. For ease of explanation, in the following embodiment PFC**1**, PFC**2**, PFE**1**, and PFE**2** are implemented as software instructions executed by the LCD.

(111) PFE **1** can receive a signal of reference power flow of Energy Source **1 202** P.sub.ES1, REF from a main Power Management Controller (not shown) located in the MCD **112** based on the load power requirements and status of Energy Source **1** of this specific ConSource V**3** module **108**C. PFE**1** can also receive the signal P.sub.LOAD1, determined by power consumption and/or generation of Auxiliary Load **1 408** and obtained in power calculation block (not shown in FIG. **13**), based on the current in Auxiliary Load **1** (e.g., measured by a current sensor which can be integrated in ConSource V**3** module or received by the LCD directly from Auxiliary Load **1**). The total reference power flow for Energy Source **1 202** P.sub.TOT_REF_ES1 can be a sum of P.sub.ES1, REF and P.sub.LOAD1. PFC **1 1310** can estimate a maximum allowable charge and/or discharge current of Energy Source **1** and calculate a real permissible power flow P.sub.TOT,ES1 of Energy Source **1**.

(112) PFE **2 1320** can receive a signal of total power flow of Energy Source **1** P.sub.TOT,ES1 from PFC **1**. PFE**2** can receive also the signal P.sub.LOAD2, determined by power consumption and/or generation of Auxiliary Load **2** and obtained in a power calculation block (not shown in FIG. **13**), based on the current in Auxiliary Load **2** (e.g., measured by a current sensor, which can be integrated in ConSource V**3** module or received by the LCD directly from Auxiliary Load **2**). The total reference power flow for ConSource V**3** module with two Auxiliary loads P.sub.CONSOURCE can be the sum of P.sub.LOAD2 and P.sub.TOT,ES1. The total P.sub.CONSOURCE power flow is provided by the switching portions of the various Converters V**2**, each of which includes switches S**3**, S**4**, S**5**, S**6**. The power flow P.sub.LOAD2 can be managed by the switching portion of Converter V**2** that includes switches S**1**, S**2** and coupling inductor L.sub.C.

(113) The LCD **114** for ConSource V**3** module **180**C is shown in FIG. **4**. It can be connected to ConSource V**2** module **108**B via a set of diagnostics, measurement, protection and control signal lines, and can perform at least one of, preferably all of, four major functions. The first function can be management of Energy Source **1 202**. The second function can be management of Auxiliary Load **2 410**. The third function can be protection of the Energy Buffer **204** and more specifically its components from over-current, over-voltage and high temperature. The fourth function can be control and protection of Converter V**1**.

(114) In some example embodiments, the function of management of Energy Source **1 202** for

ConSource V**3** module **108**C can be as follows. The LCD **114** accepts the measurement signals VES**1**, TES**1**, IES**1**, which are: VES**1**—the voltages of all elementary components/cells of Energy Source **1 202** or the voltages of groups of elementary components/cells, such as, for example, but not limited to, battery cells, individual or connected in series and/or in parallel, ultra-capacitor cells, individual, or connected in series and/or in parallel; TES**1**—the temperatures of all elementary components of Energy Source **1** or the temperatures of groups of elementary components; IES**1**—the output current of Energy Source **1**. Based on these measurement signals LCD can perform the following: calculates a real capacity, actual State of Charge (SOC) and State of Health (SOH) of the elementary components or groups of elementary components; set a warning or alarm signal based on measured and calculated data; transmission of corresponding signals to the MCD.

(115) The function of management of Auxiliary Load **2 410** for ConSource V**3** module **108**C can be as follows. The LCD receives the measurement signals VAL**2**, IAL**2**, which are: VAL**2**—the voltage between ports **5** and **6** of ConSource V**3** module, and IAL**2**—the current in coupling inductor LC of Converter V**2**, which is a current of Auxiliary Load **2**. In some embodiments, the LCD reports these signals (or representations thereof) to the MCD, which performs correction by adjusting the modulation index of the module **108**C. In other embodiments, based on these signals the LCD performs a correction of the reference signal for pulse width modulation in the LCD to stabilize and/or to control the voltage on Auxiliary Load **2**.

(116) The function of protection of Energy Buffer **204** for ConSource V**3** module **108**C can be as follows. The LCD can receive the measurement signals VEB, TEB, IEB, which are: VEB—the voltages of at least one major component of Energy Buffer, for example and not limited to, capacitor CEB, or capacitors CEB**1**, CEB**2** (see FIGS. **7**A-**7**C); TEB—the temperature of at least one major components of Energy Buffer **204**; IEB—the current through at least one major components of Energy Buffer **204**. Based on these measurement signals LCD can perform the following: set a fault (e.g., warning or alarm) signal based on measured data; and/or transmit corresponding fault signals to the MCD.

(117) The function of control and protection of Converter V**2 308** for ConSource V**3** module **108**C can be as follows. The LCD **114** receives the command signals from the MCD **112**, which can be a modulation reference signal and enable signal, or a reference signal and a modulation index, which can be used in a PWM and/or a Hysteresis function in the LCD to generate the control signals for semiconductor switches S**1**, S**2**, S**3**, S**4**, S**5**, S**6** in accordance to power management and/or second order harmonic reduction techniques described above. The current feedback signals IES**2**, TOUT coming from integrated current sensors of Converter V**2** (not shown in FIG. **4**) can be used for overcurrent protection together with one or more signals F, coming from driver circuits (not shown in FIG. **4**), of semiconductor devices of Converter V**2**, which carry the information about failure statuses (e.g., short circuit or open circuit failure mode) of one or more, preferably all, of the semiconductor switches. Based on this specific data, the LCD can make a decision on which combination of switching signals S**1**, S**2**, S**3**, S**4**, S**5**, S**6** to be applied to the corresponding semiconductor switches to bypass or disconnect the Converter V**2 308** and the entire ConSource V**3** module from system **100** (e.g., the battery pack, etc.).

(118) One example of a ConSource module is a converter-battery module having a battery as the first energy source. A converter-battery module can be referred to as a ConBatt module. A ConBatt module can be used in, e.g., a battery pack of a mobile application such as an electric vehicle (EV). System **100**, configured for use as a battery pack with a plurality of ConBatt modules, can be referred to as a ConBatt pack.

(119) In other example embodiments, the ConSource modules can connect with additional sources of electrical power, such as photovoltaic panels and/or a wireless charging receiver. In other example embodiments, system **100** can connect to another system **100** (e.g., another ConBatt pack) coupled with other auxiliary loads of different voltage levels, such as, e.g., an EV's on-board

electrical network system and air-conditioner.

(120) The features of one example embodiment of ConSource modules V**1**, V**2**, or V**3** can be combined with the features of another example embodiment of ConSource modules V**1**, V**2**, or V**3** as desired. For example, ConSource modules V**1** and V**2** can each be configured to supply Auxiliary Loads **1** and/or **2** as described with respect to ConSource module V**3**. By way of another example, ConSource modules V**1** and V**3** can each be configured with a second energy source (Energy Source **2**) as described with respect to ConSource module V**2**.

Example Embodiments of Module Arrangements for Module-Based Systems

(121) FIGS. **15-29** depict example embodiments of system **100** arranged according to various architectures or configurations. In these embodiments system **100** can be configured as one or more module packs, although the embodiments are not limited to packs. For ease of illustration, the MCD and the LCDs in each embodiment are not shown. As can be seen, the modules can be arranged in numerous ways such that the power contributed by each module can be summed to form one or more of, e.g., a single phase AC output, multiple phases of AC outputs, and a DC output.

(122) FIG. **15** shows an example embodiment of a ConSource pack **1500** including a one-dimensional array of N number of connected ConSource modules **108**-1, **108**-2 . . . **108**-N according to the present disclosure. The one dimensional array can also be referred to as a cascade of N stages, where each stage corresponds to one module **108**. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing. Each of the ConSource modules in the array may be configured according to any one of the three module versions (V**1**, V**2** and V**3**) discussed above with regard to FIGS. **2**, **3** and **4**. The plurality of ConSource modules may include modules configured according to the same module version (V**1**, V**2** or V**3**) or a mixture of modules configured according to two or more of the three module versions (V**1**, V**2** and V**3**). A first port **1** of an ConSource V**1**/V**2**/V**3** module of a first row of the one-dimensional array ("first ConSource V**1**/V**2**/V**3** module") is connected to a first output terminal out**1** of the one-dimensional array of ConSource modules. A second port **2** of the first ConSource V**1**/V**2**/V**3** module is connected to a first port **1** of a ConSource V**1**/V**2**/V**3** module in a second row ("second ConSource V**1**/V**2**/V**3** module"). A second port **2** of the second ConSource V**1**/V**2**/V**3** module is connected to a first port of ConSource V**1**/V**2**/V**3** module in a third row ("third ConSource V**1**/V**2**/V**3** module") and so on in the same order further down to a Nth ConSource V**1**/V**2**/V**3** module in an Nth or last row. A second port **2** of the Nth ConSource V**1**/V**2**/V**3** module is connected to a second output terminal out **2** of the one-dimensional array **1500**. This one-dimensional array of N number of connected ConSource modules can be used as a DC or single phase AC energy source, such as, e.g., a battery pack, for stationary energy storage applications for DC or AC single-phase loads. A DC or AC single-phase load can be connected between the first and second output terminals out**1** and out**2**.

(123) The output voltage of the one-dimensional array of N number of connected ConSource modules can be generated using, for example, but not limited to, space vector modulation or sine pulse width modulation ("PWM") with a Phase Shifted Carrier technique. The switching signals for each of the ConSource modules' Converter may then be generated using Phase Shifted Carrier technique. This technique ensures that the ConSource modules are continuously rotated and the power is almost equally distributed among them.

(124) The example purpose of a phase shifted technique is to generate a multilevel output PWM waveform using incrementally shifted two-level waveforms. Therefore an X-level PWM waveform is created by the summation of $(X-1)/2$ two-level PWM waveforms. These two-level waveforms are generated by comparing the reference waveform Vref to triangular carriers **1400**, **1410** (FIGS. **14**A, **14**B) that are incrementally shifted by $360°/(X-1)$. A 9-level example **1400** is shown in FIG. **14**A (using four modules **108**). The carriers are incrementally shifted by $360°/(9-1)=45°$ and compared to the reference waveform. The resulted two-level PWM waveforms **1420** are shown in

FIG. **14**C. These two-level waveforms may be used as the switching signals for semiconductor switches of the Converters in each ConSource module **108**. As an example, for a one-dimensional array including four cascaded ConSource modules, each having a Converter V**1** (with S**3**, S**4**, S**5**, S**6** arranged in an H-bridge), the 0° signal is used for S**3** and 180° signal for S**6** of the first ConSource module, the 45° signal is used for S**3** and 225° signal for S**6** of the second ConSource module, and so on. Note that in all of Converters V**1**/V**2**/V**3**, the signal for S**3** is complementary to S**4** and the signal for S**5** is complementary to S**6** along with certain dead-time to avoid shoot through of each leg. FIG. **14**D depicts an example AC waveform produced by superposition of output voltages from the four modules.

(125) Depending on the resources and limitations of the hardware that is used to implement the modulation, an alternative is to generate the negative reference signal along with the first (N−1)/2 carriers. The 9-level example is shown in FIG. **14**B. In this case, the 0° to 135° PWM signals are generated by comparing Vref to the corresponding carriers and the 180° to 315° PWM signals are generated by comparing −Vref to carriers of 0° to 135°. However, the logic of the comparison in the latter case must be reversed. Other techniques such as a state machine decoder may also be used to generate the gate signals for the H-bridges.

(126) In multi-phase system embodiments, the same carriers can be used for each phase, or the set of carriers can be shifted as a whole for each phase. For example, in a three phase system each phase array can use the same number of carriers with the same relative offsets as shown in FIGS. **14**A and **14**B, but the carriers of the second phase are shift by 120 degrees as compared to the carriers of the first phase, and the carriers of the third phase are shifted by 240 degrees as compared to the carriers of the first phase. In many cases the carrier frequencies will be fixed, but in some example embodiments, the carrier frequencies can be adjusted. Adjustment of the carrier frequencies can help to reduce losses in an EV motor under high current conditions.

(127) This one-dimensional array **1500** embodiment of system **100** shown in FIG. **15** enables obtaining a high voltage of any shape with very low total harmonic distortion between first and second terminals out **1** and out **2** using low and/or medium voltage rated energy source elements and switching components (MOSFETs, JFETs, IGBTS, etc.) with significantly reduced switching and conduction losses in the ConSource modules.

(128) FIG. **16** shows an example embodiment of a first version of a ConSource pack including a two-dimensional array **1600** or two one-dimensional arrays **1500** of N number of connected ConSource V**1**/V**2**/V**3** modules **108**-1, **108**-2 . . . **108**-N according to the present disclosure. Output of DC or AC voltage generation of each of the two one-dimensional arrays **1500**, which form this two-dimensional array **1600**, is described above with regard to FIG. **15**. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing. A second port **2** of each of an Nth ConSource V**1**/V**2**/V**3** module in Nth or last rows of both of the one-dimensional arrays are connected together and to a common output terminal Out**3** of the two-dimensional array. Output voltages are provided between first and second output terminals Out**1** and Out**2** and the common output terminal Out**3**.

(129) This two-dimensional array of 2N number of connected ConSource V**1**/V**2**/V**3** modules can be used as a two-phase AC energy source for stationary energy storage applications for DC or AC single-phase loads. The load can be connected between first and second output terminals Out**1** and Out**2**, while the common terminal Out**3** can be connected to a neutral of the load, if required.

(130) The first and second output terminals out**1** and out**2** of the example two-dimensional array based ConSource pack can be connected together via coupling inductors and connected to the same first terminal of an AC or DC load, when the common output terminal out**3** is connected to the second terminal of the AC or DC load. In this case the output power capability of such two-dimensional array based ConSource pack with N rows is two times higher than one of the single-dimensional array based ConSource pack with the same number N of rows.

(131) This two-dimensional array embodiment of system **100** shown in FIG. **16**, enables obtaining

a two phase system of high voltages with 90 degree phase displacement. For example, such systems can be used in electrical furnaces. In general, the high voltages of any shape with very low total harmonic distortion can be obtained between terminals out**1**, out**2** and common terminal out**3**, which can serve as a Neutral, using low and/or medium voltage rated energy source elements and switching components (MOSFETs, JFETs, IGBTS, etc.) with significantly reduced switching and conduction losses in the ConSource modules.

(132) FIG. **17** shows an example embodiment of a second version of a ConSource pack including a two-dimensional array **1700** or two one-dimensional arrays of N and N+1 numbers of connected ConSource modules **108**-1, **108**-2 . . . **108**-N according to the present disclosure. Output of DC or AC voltage generation of each of the two one-dimensional arrays **1500** with N and N+1 numbers of interconnected ConSource modules, which form this two-dimensional array, is described above with regard to FIG. **15**. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing. A second port **2** of each of an Nth ConSource V**1**/V**2**/V**3** module in Nth or last rows of both of the one-dimensional arrays are connected to first and second ports **1** and **2** of an additional or N+1th ConSource V**1**/V**2**/V**3** module.

(133) This two-dimensional array of 2N+1 number of connected ConSource V**1**/V**2**/V**3** modules can be used as a single-phase AC energy source for stationary energy storage applications for DC or AC single-phase loads. The load can be connected between first and second output terminals Out**1** and Out**2** of a first ConSource V**1**/V**2**/V**3** module in a first row of each of the one-dimensional arrays.

(134) FIG. **18** shows an example embodiment of a first version of a ConSource pack including a plurality of ConSource V**1**/V**2**/V**3** modules **108**-1, **108**-2 . . . **108**-N, connected in a three-dimensional array **1800**, according to the present disclosure. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing. First, second and third output terminals out**1**, out**2** and out**3** of the ConSource pack are connected to a first port **1** of a first ConSource V**1**/V**2**/V**3** module of a first row of each of the three one-dimensional arrays **1500**, which form this three-dimensional array **1800** based ConSource pack. Output of DC or AC voltage generation of each of the three one-dimensional arrays **1500**, which form this three-dimensional array **1800** based ConSource pack, is described above with regard to FIG. **15**. A second port **2** of an Nth ConSource V**1**/V**2**/V**3** module in an Nth or last row of each of the three one-dimensional arrays are connected together and to a common output terminal out**4** of the three-dimensional array. The output voltages are provided between the first, second and third output terminals out**1**, out**2**, out**3** and the common output terminal out**4**.

(135) This three-dimensional array **1800** of 3N connected ConSource V**1**/V**2**/V**3** modules **108**-1, **108**-2 . . . **108**-N can be used as a three-phase AC energy source for stationary energy storage or electric vehicle applications for DC or AC single load, three-phase loads, three phase power grids or three-phase electric motors **2200**, as shown in FIG. **22**. The three-phase load can be connected between the first, second and third output terminals out**1**, out**2**, out**3**, while the common output terminal out**4** can be connected to a neutral of the load, if required.

(136) The first, second and third output terminals out**1**, out**2** and out**3** of the three-dimensional array based ConSource pack can be connected together via coupling inductors and connected to the same first terminal of a DC or single-phase AC load, when the common output terminal out**4** is connected to the second terminal of the DC or single phase AC load. In this case, the output power capability of such three-dimensional array based ConSource pack with N rows is three times higher than the one single-dimensional array based ACi-battery pack with the same number N of rows.

(137) This three-dimensional array **1900** embodiment of system **100** shown in FIG. **19** enables obtaining three-phase system of high voltages of any shape with very low total harmonic distortion between terminals out**1**, out**2**, out**3** and common terminal out**3** which can serve as a Neutral, using

low and/or medium voltage rated energy source elements and switching components (MOSFETs, JFETs, IGBTS, etc.) with significantly reduced switching and conduction losses in the ConSource modules. Such a system can be connected to the power distribution grid and can be used as an active power source or buffer, reactive power compensator and power factor corrector, active harmonic filter with very high dynamic response and significantly reduced size of passive filter between out**1**, out**2**, out**3** and the phases of power grid. This system can also be connected to three-phase load providing the energy from energy source elements such as batteries, supercapacitors, fuel-cells, etc.

(138) FIG. **19** shows an example embodiment of a second version of a ConSource pack including a plurality of ConSource modules **108**-1, **108**-2 . . . **108**-N, connected in a three-dimensional array **1900** according to the present disclosure. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing.

(139) A first port **1** of a ConSource V**1**/V**2**/V**3** module **108**-1 of a first row ("first ConSource V**1**/V**2**/V**3** module") of each of the three one-dimensional arrays **1500** are connected to first, second and third output terminals out**1**, out**2** and out**3** of each of the three one-dimensional arrays, which form this three-dimensional array based ConSource pack. Output DC or AC voltage generation of each of the three one-dimensional arrays with N number of connected ConSource V**1**/V**2**/V**3** modules, which form this three-dimensional array, is described above with regard to FIG. **15**. A second port **2** of the first ConSource V**1**/V**2**/V**3** modules **108**-1 are connected to first ports **1** of ConSource V**1**/V**2**/V**3** modules **108**-2 in second rows of the three one-dimensional arrays ("second ConSource V**1**/V**2**/V**3** modules"). Second ports **2** of the second ConSource V**1**/V**2**/V**3** modules are connected to first ports **1** of ConSource V**1**/V**2**/V**3** modules in third rows (not shown) of the three one-dimensional arrays and so on in the same order further down for M number of rows of ConSource V**1**/V**2**/V**3** modules, wherein M is 2 or greater.

(140) First ports **1** of ConSource V**1**/V**2**/V**3** modules of M+1th rows are connected to second ports **2** of ConSource V**1**/V**2**/V**3** modules of Mth rows (not shown). Second ports **2** of ConSource V**1**/V**2**/V**3** modules in the M+1th rows are connected to first ports **1** of ConSource V**1**/V**2**/V**3** modules in M+2th rows (not shown). Second output ports **2** of ConSource V**1**/V**2**/V**3** modules in the M+2th rows are connected to first ports **1** of ConSource V**1**/V**2**/V**3** modules in M+3th rows (not shown) and so on in the same order further down for M+N number of rows of ConSource V**1**/V**2**/V**3** modules.

(141) A second port **2** of a ConSource V**1**/V**2**/V**3** module in a last row or M+Nth row of a first column **1500** of the three-dimensional array is connected to the first port **1** of the ConSource V**1**/V**2**/V**3** module of the M+1 row of a second column **1500′** of the three-dimensional array. A second port **2** of a ConSource V**1**/V**2**/V**3** module in a last row or M+Nth row of the second column of the three-dimensional array is connected to the first port **1** of the ConSource V**1**/V**2**/V**3** module of the M+1 row of a third column **1500″** of the three-dimensional array. A second port **2** of a ConSource V**1**/V**2**/V**3** module in a last row or M+Nth row of the third column of three-dimensional array is connected to the first port **1** of a ConSource V**1**/V**2**/V**3** module of a M+1 row of the first column of the three-dimensional array.

(142) This three-dimensional array of connected ConSource V**1**/V**2**/V**3** modules can be used as a three-phase energy source for stationary energy storage or electric vehicle applications for DC or AC single load, three-phase loads, three phase power grids or three-phase electric motors, as shown in FIG. **23**.

(143) In addition to the advantages mentioned with regard to FIG. **18**, this three-phase (three-dimensional array) configured embodiment of system **100** shown in FIG. **19**, with a combination of series connected and delta connected ConSource modules, enables an effective exchange of energy between all ConSource modules of the system (inter-phase balancing) and phases of power grid or load. A combination of delta and series connected ConSource modules allow reducing the total

number of ConSource modules in array to obtain the desired output voltages.

(144) FIG. **20** shows an example embodiment of a third version of a ConSource pack including a plurality of ConSource modules, connected in a three-dimensional array **2000** according to the present disclosure. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing. First, second and third output terminals out**1**, out**2** and out**3** of the ConSource pack are connected to first ports **1** of ConSource V**1**/V**2**/V**3** modules **108**-1 of first rows of the three one-dimensional arrays **1500**, which form this three-dimensional array **2000** based ConSource pack. Output DC or AC voltage generation of each of the three one-dimensional arrays with N number of connected ConSource V**1**/V**2**/V**3** modules **108**-1, **108**-2 . . . **108**-N, which form this three-dimensional array, is described above with regard to FIG. **15**. A second port **2** of a ConSource V**1**/V**2**/V**3** module of an Nth row of a first column of the three-dimensional array is connected to a first port **1** of a first additional ConSource V**3** module, employed as an interconnection (IC) module **108**-IC of an N+1th row. A second port **2** of a ConSource V**1**/V**2**/V**3** module of an Nth row of a second column of the three-dimensional array is connected to a second port **2** of the first additional ConSource V**3** module **108**-IC of the N+1th row. A second port **2** of a ConSource V**1**/V**2**/V**3** module of an Nth row of a third column of the three-dimensional array is connected to a first port **1** of a second additional ConSource V**3** module **108**-IC of an N+1th row. A second port **2** of the second additional ConSource V**3** module is connected to a fourth output terminal Out**4** of the ConSource pack. Third and fourth ports **3** and **4** of the first and second additional ConSource V**3** modules of the N+1th rows are interconnected as shown in FIG. **20**.

(145) This three-dimensional array of connected ConSource V**1**/V**2**/V**3** modules can be used as a three-phase energy source for stationary energy storage or electric vehicle applications for DC or AC single load, three-phase loads, three phase power grids or three-phase electric motors, as shown in FIG. **24**. The three-phase load can be connected between the first, second and third output terminals out**1**, out**2** and out**3**, while the fourth output terminal out**4** can serve as one a charging terminal.

(146) In addition to the advantages mentioned with regard to FIG. **18**, this three-phase (three-dimensional array) configured embodiment of system **100** shown in FIG. **20**, with two additional interconnection ConSource V**3** modules **108**-IC, enables an effective and fast exchange of energy between all ConSource modules of the system (inter-phase balancing) and phases of power grid or load.

(147) FIG. **21** shows an example embodiment of a fourth version of a ConSource pack including a plurality of ConSource modules, connected in a multi-dimensional array **2100** including K one-dimensional arrays **1500** according to the present disclosure, where K, as an example, is 3 or greater, and illustrated in an example orientation having a plurality of rows and K columns for presentation and reference purposes only. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing. Each of the K one-dimensional arrays **1500** include M+N ConSource V**1**/V**2**/V**3** modules **108**-1 . . . **108**-(M+N) having first and second ports. Each of the first, Kth and other odd integer one dimensional arrays include an M+N+1th additional ConSource V**3** module **108**-IC having first, second, third and fourth ports.

(148) The first ports **1** of ConSource V**1**/V**2**/V**3** modules of first rows of each of the K number of one-dimensional arrays, respectively, are connected to individual ones of first and second output terminals out**1** and out**2** and so on out to a Kth output terminal outK of the K number of one-dimensional arrays, which form this multi-dimensional array based ConSource pack. The second ports **2** of the ConSource V**1**/V**2**/V**3** modules in the first rows are connected to the first ports **1** of ConSource V**1**/V**2**/V**3** modules in second rows (not shown) of each of the K number of one-dimensional arrays. The second ports **2** of the ConSource V**1**/V**2**/V**3** modules in the second rows are connected to the first ports **1** of ConSource V**1**/V**2**/V**3** modules in third rows (not shown) of

each of the K number of one-dimensional arrays, and so on in the same order further down for a M number of rows of ConSource V1/V2/V3 modules, where M is 2 or greater.

(149) The second port2 of a ConSource V1/V2/V3 module 108-M of a first array column of an Mth row is connected to the first port 1 of a ConSource V1/V2/V3 module 108-1 of a second array column of the first row. The second port2 of a ConSource V1/V2/V3 module 108-M of the second array column of the Mth row is connected to the first port 1 of a ConSource V1/V2/V3 module 108-1 of a third array column of the first row, and so on in the same order to a Kth array column, where the second port2 of a ConSource V1/V2/V3 module 108-M in the Kth array column of the Mth row is connected to the first port 1 of the ConSource V1/V2/V3 module 108-1 of the first array column of the first row.

(150) The first ports 1 of ConSource V1/V2/V3 modules 108-(M+1) of all of the first through Kth array columns of M+1th rows are connected to the second ports 2 of the ConSource V1/V2/V3 modules 108-M of the Mth rows. The second ports 2 of ConSource V1/V2/V3 modules 108-(M+1) of all of the first through Kth array columns of the M+1th rows are connected to the first ports 1 of ConSource V1/V2/V3 modules of all of the first through Kth columns of M+2th rows, and so on in the same order further down for an N number of rows of ConSource V1/V2/V3 modules, where N is 2 or greater.

(151) The second port 2 of a ConSource V1/V2/V3 module of an M+Nth row of the first array column of the multi-dimensional array is connected to the first port 1 of a first additional ConSource V3 module of an M+N+1th row. The second port 2 of a ConSource V1/V2/V3 module of the M+Nth row of the second array column of the multi-dimensional array is connected to the second port 2 of the first additional ConSource V3 module of the M+N+1th row. The second port 2 of a ConSource V1/V2/V3 module of the M+Nth row of a K−2th array column of the multi-dimensional array is connected to the first port 1 of a ((K−1)/2)th additional ConSource V3 module of the M+N+1th row. The second port 2 of a ConSource V1/V2/V3 module of the M+Nth row of a K−1th column of the multi-dimensional array is connected to the second port 2 of the ((K−1)/2)th additional ConSource V3 module of the M+N+1th row. The second port 2 of a ConSource V1/V2/V3 module of the M+Nth row of the Kth column of the multi-dimensional array is connected to a first port 1 of a (K+1)/2 the additional ConSource V3 module of M+N+1th row. The second port 2 of the (K+1)/2th additional ConSource V3 module is connected to a Kth output terminal outK+1 of the ConSource pack. The output ports 3 and 4 of all (K+1)/2 additional ConSource V3 modules of M+N+1th rows are connected together as shown in FIG. 21.

(152) This multi-dimensional array of connected ConSource V1/V2/V3 modules can be used as a multi-phase energy source for stationary energy storage or electric vehicle applications, for DC load, multi-phase AC loads, multi-phase power grids or multi-phase electric motors.

(153) In addition to the advantages mentioned with regard to FIG. 18, this multi-dimensional array 2100 embodiment of system 100 shown in FIG. 21, with a combination of delta connected and series connected ConSource modules and additional interconnection ConSource V3 modules, enables an effective and fast exchange of energy between all ConSource modules of the system (inter-phase balancing) and phases of power grid or load. A combination of delta and series connected ConSource modules allow reducing the total number of ConSource modules in array to obtain the desired output voltages.

(154) FIG. 22 and FIG. 23 shows example embodiments of first and second versions of ConSource packs 1800, 1900, respectively, as presented in FIG. 18 and FIG. 19, respectively, and further connected to a three-phase electrical motors 2200 of any type. All of the modules 108 shown in FIG. 22 can, if desired, be combined in a single energy pack, where the modules 108 are co-located in a single common enclosure or housing. The same applies for all of the modules 108 shown in FIG. 23.

(155) The three-dimensional array 1800 (three-phase motor drive system) embodiment of system 100 shown in FIG. 22, enables obtaining a three-phase system of high voltages of any shape with

very low total harmonic distortion between motor phases A, B and C, using low and/or medium voltage rated energy source elements and switching components (MOSFETs, JFETs, IGBTS, etc.) with significantly reduced switching and conduction losses. Such a system does not require a usage of bulky passive filters as in case of 2-level inverter and has a high dynamic response.

(156) In addition to the advantages mentioned with regard to FIG. **22**, the three-phase motor drive embodiment **1900** of system **100** (three-dimensional array) shown in FIG. **23**, with a combination of series connected and delta connected ConSource modules **108**, enables an effective exchange of energy between all ConSource modules of the system (inter-phase balancing) and all phases of electric motor **2200**. A combination of delta and series connected ConSource modules allow reducing the total number of ConSource modules in array to obtain the desired output motor voltages.

(157) FIG. **24** shows an example embodiment of a third version of a ConSource pack connected to a three-phase electrical motor **2200** of any type. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing. The ConSource pack is as presented in FIG. **21**, where K equals 3, with the third and fourth output ports **3** and **4** of the two additional ConSource V**3** modules **108**-IC of the N+1th rows connected together and to a second Auxiliary Load **2**. The two additional ConSource V**3** modules of the N+1th rows further include fifth and sixth output ports **5** and **6** connected together and to a first Auxiliary Load **1 408**. The first Auxiliary Load **1** and the second Auxiliary Load **2 410** have different voltages and represent, for example, but not limited to, electric vehicle's onboard network system and air-conditioner power supply system, respectively.

(158) In addition to the advantages mentioned with regard to FIG. **21**, this three-phase motor drive embodiment **2400** of system **100** (three-dimensional array) shown in FIG. **24**, with a combination of series connected and delta connected ConSource modules **108** and two additional interconnection ConSource V**3** modules **108**-IC, enables an effective and fast exchange of energy between all ConSource modules of the system (inter-phase balancing) and phases of electric motor **2200**. A combination of delta and series connected ConSource modules allow reducing the total number of ConSource modules in array to obtain the desired output motor voltages. The additional output terminals **3**, **4**, **5**, **6** of interconnection ConSource V**3** modules provide low voltages of different levels, which can be used to provide a power for auxiliary loads, which in turn represent, for example, the electrical on-board network and HVAC power line of an electric vehicle. In this case an extra low-voltage battery is not required; the energy for above mentioned systems is delivered by entire array of ConSource modules.

(159) FIG. **25** shows an example embodiment **2500** of a fourth version of a ConSource pack connected to a three-phase electrical motor **2200** of any type. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing. The ConSource pack is as presented in FIG. **20** with the third and fourth output ports **3** and **4** of the two additional ConSource V**3** modules **108** of the N+1th rows connected together and to a second Auxiliary Load **410**. The two additional ConSource V**3** modules of the N+1th rows further include fifth and sixth output ports **5** and **6** connected together and to a first Auxiliary Load **408**. The first Auxiliary Load **408** and second Auxiliary Load **410** have different voltages and represent, for example, but not limited to, electric vehicle's onboard network system and air-conditioner power supply system, respectively.

(160) In addition to the advantages mentioned with regard to FIG. **22**, this three-phase motor drive embodiment of system **100** (three-dimensional array) shown in FIG. **25**, with two additional interconnection ConSource V**3** modules **108**-IC, enables an effective and fast exchange of energy between all ConSource modules of the system (inter-phase balancing) and phases electric motor. The additional output terminals **3**, **4**, **5**, **6** of interconnection ConSource V**3** modules **108**-IC provide low voltages of different levels, which can be used to provide power for auxiliary loads, which in turn represent, for example, the electrical on-board network and HVAC power line of an

electric vehicle. In this case an extra low-voltage battery is not required; the energy for above mentioned systems is delivered by entire array of ConSource modules.

(161) FIG. **26** shows an example embodiment **2600** of a fifth version of a ConSource pack connected to six-phase electrical motor **2650** of any type. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing. The ConSource pack is as presented in FIG. **25** with the first and second array columns of the three dimensional array **2500** repeat twice to form six array columns of a six dimensional array including 3 sets of the first and second array columns shown in FIG. **25**. The third and fourth ports **3** and **4** of the three additional ConSource V**3** modules **108**-IC of the N+1 rows are connected together and to the second Auxiliary Load **2 410** and the fifth and sixth ports **5** and **6** of the three additional ConSource V**3** modules **108**-IC of the N+1th rows are connected together and to the first Auxiliary Load **1 408**. The first Auxiliary Load **408** and the second Auxiliary Load **410** have different voltages and represent, for example, but not limited to, electric vehicle's onboard network system and air-conditioner power supply system, respectively.

(162) In addition to the advantages mentioned with regard to FIG. **22**, this three-phase motor drive embodiment of system **100** (three-dimensional array) shown in FIG. **26**, with three additional interconnection ConSource V**3** modules **108**-IC, enables an effective and fast exchange of energy between all ConSource modules of the system (inter-phase balancing) and all six phases electric motor. The additional output terminals **3**, **4**, **5**, **6** of interconnection ConSource V**3** modules provide low voltages of different levels, which can be used to provide power for auxiliary loads, which in turn represent, for example, the electrical on-board network and HVAC power line an electric vehicle. In this case an extra low-voltage battery is not required; the energy for above mentioned systems is delivered by entire six-dimensional array of ConSource modules.

(163) FIG. **27**A shows an example embodiment of a sixth version of system **100**, having two ConSource systems **2700** and **2700′** each including N rows of ConSource modules connected in three-dimensional array. System **2700** is configured to be the primary electrical supply for three-phase electrical motor **2200**, while system **2700′** is configured to be the primary electrical supply for three phase electrical motor **2200′**. Both systems **2700** and **2700′** can operate with different voltages and frequencies. System **2700** includes an N+1th row of IC modules **108**-IC, which are coupled to auxiliary loads and the Nth row of modules **108**-N of system **2700′**.

(164) Each system **2700**, **2700′** can be independently configured as a single common electrical and mechanical unit, or pack, with modules **108** placed adjacent or in close proximity with each other, and sharing the same cooling system. Each of packs **2700**, **2700′** can be located in its own separate and independent enclosure or housing **2705**, **2705′**, respectively. In other embodiments, all of the modules **108** shown in FIG. **27**A can be combined as one common pack. In yet another embodiment, any of the aforementioned configurations can be used, but with the IC modules **108**-IC in one or more separate packs apart from the pack(s) holding the other cascaded modules **108**.

(165) The first, second and third terminals A, B and C of a first Motor **1 2200** are connected to the ConSource pack at the first ports **1** of ConSource V**1**/V**2**/V**3** modules **108**-1 of a first row of pack **2700**. The second ports **2** of ConSource V**1**/V**2**/V**3** modules of the Nth row of all three array columns of pack **2700** are connected to the first ports **1** of three corresponding IC modules **108**-IC of the N+1th row, as shown in FIG. **27**A. The second ports **2** of all three of the IC modules **108**-IC of the N+1th row are connected to the second ports **2** of the ConSource V**1**/V**2**/V**3** modules **108**-N of the Nth row of pack **2700′**. The first, second and third output terminals A′, B′ and C′ of Motor **2200′** are connected to the first ports **1** of the ConSource V**1**/V**2**/V**3** modules of the 1st row of the ConSource pack **2700′**. The second ports **2** of the ConSource V**1**/V**2**/V**3** modules **108**-1 of the 1st row are connected to the second ports **2** of ConSource V**1**/V**2**/V**3** modules **108**-2 of the second row of pack **2700′**, and so on in the same order further down to the last row or Nth row of pack **2700′**, as shown in FIG. **27**A.

(166) The third and fourth ports **3** and **4** of the IC modules **108**-IC are connected together and to a

first Auxiliary Load **408**. The fifth and sixth ports **5** and **6** of the three IC modules **108**-IC are connected together and to a second Auxiliary Load **410**. The first Auxiliary Load and the second Auxiliary Load have different voltages and represent, for example, but not limited to, an electric vehicle's onboard network system and air-conditioner power supply system, respectively.

(167) This three-dimensional array embodiment of system **100** with three additional interconnection ConSource V**3** modules **108**-IC shown in FIG. **27**A, provides the independent voltage and frequency regulation (control) for at least two independent motors (e.g., a dual-motor drive system) and enables an effective and fast exchange of energy (inter-phase balancing) between all ConSource modules of such a dual-motor system and phases of two electric motors. The additional output terminals **3**, **4**, **5**, **6** of interconnection ConSource V**3** modules provide low voltages of different levels, which can be used to provide power for auxiliary loads, which in turn represent, for example, the electrical on-board network and HVAC power line of an electric vehicle. In this case an extra low-voltage battery is not required; the energy for above mentioned systems is delivered by entire array of ConSource modules. In this embodiment the IC modules **108**-IC are shown as being part of pack **2700**, but in other embodiments the IC modules **108**-IC can be outside of packs **2700** and **2700′**, either as independent entities or in a third pack containing the three IC modules **108**-IC. The configuration of FIG. **27**A can be used in multiple stationary and mobile applications, including EV's having two in-wheel motors **2200** and **2200′**, which could be motors to the two front wheels (front wheel drive) or two rear wheels (rear wheel drive). Regardless of whether Auxiliary Loads **408** and **410** are supplied, this embodiment permits inter-phase balancing between phases within each individual system and across the two systems (e.g., inter-system or inter-pack balancing).

(168) FIG. **27**B shows another example embodiment of system **100**, where the system described with respect to FIG. **27**A has been duplicated to implement four systems **2750**, **2750′**, **2750″**, **2750′″** as primary supplies for four motors **2200**, **2200′**, **2200″**, **2200′**, respectively. Each system **2750**, **2750′**, **2750″**, **2750′″** includes a number of rows of modules **108** connected in three-dimensional array, where system **2750** has N rows, system **2750′** has M rows, system **2750″** has P rows, and system **2750′** has Q rows. The number of rows (and hence cascaded stages) in each system can be different, although in many embodiments the number of rows can be the same (N=M=P=Q). All four systems can operate with different voltages and frequencies. System **2750** includes an N+1th row of modules **108**-IC, implemented as IC modules, which are coupled to Auxiliary Loads **1** and **2** and the Mth row of modules **108** of system **2750′**. System **2750″** includes an P+1th row of modules **108**-IC, implemented as IC modules, which are also coupled to Auxiliary Loads **1** and **2** and the Qth row of modules **108** of system **2750″**.

(169) Each system **2750**, **2750′**, **2750″**, **2750′″** can be independently configured as a single common electrical and mechanical unit, or pack, with modules **108** placed adjacent or in close proximity with each other, and sharing the same cooling system. Each of packs **2750**, **2750′**, **2750″**, **2750′** can be located in its own separate and independent enclosure or housing **2705**, **2705′**, **2705″**, **2705′**, respectively. In other embodiments, all of the modules **108** shown in FIG. **27**B can be combined as one common pack, or two of the four systems can be implemented as a first pack (e.g., dedicated to front wheels of an EV) and the other two of the four systems can be implemented as a second pack (e.g., dedicated to rear wheels of the EV). In yet another embodiment, any of the aforementioned configurations can be used, but with the IC modules **108**-IC in one or more separate packs apart from the pack(s) holding the other cascaded modules **108**.

(170) The first, second and third terminals A**1**, B**1** and C**1** of motor **2200** are connected to system **2750** at the first ports **1** of ConSource V**1**/V**2**/V**3** modules **108**-1 of a first row of system **2750**. The second ports **2** of ConSource V**1**/V**2**/V**3** modules of the first row can be coupled to any number of intervening rows (not shown) in cascaded fashion as described herein, up to the first ports of the Nth row of all three array columns of system **2750**. The second ports of the Nth row of modules **108** are connected to the first ports **1** of three corresponding IC modules **108**-IC of the N+1th row,

as shown in FIG. **27**B. The second ports **2** of all three of the IC modules **108**-IC of the N+1th row are connected to the second ports **2** of the ConSource V**1**/V**2**/V**3** modules **108** of the Mth row of system **2750′**. The first, second and third output terminals A**2**, B**2** and C**2** of motor **2200′** are connected to the first ports **1** of the ConSource V**1**/V**2**/V**3** modules of the first row of the system **2750′**. The second ports **2** of the ConSource V**1**/V**2**/V**3** modules **108**-1 of the first row are connected any number of intervening rows (not shown) in cascaded fashion as described herein, up to the first ports of the Mth row of all three array columns of system **2750**.

(171) The first, second and third terminals A**3**, B**3** and C**3** of motor **2200″** are connected to system **2750″** at the first ports **1** of ConSource V**1**/V**2**/V**3** modules **108**-1 of a first row of system **2750″**. The second ports **2** of ConSource V**1**/V**2**/V**3** modules of the first row can be coupled to any number of intervening rows (not shown) in cascaded fashion as described herein, up to the first ports of the Pth row of all three array columns of system **2750″**. The second ports of the Pth row of modules **108** are connected to the first ports **1** of three corresponding IC modules **108**-IC of the P+1th row, as shown in FIG. **27**B. The second ports **2** of all three of the IC modules **108**-IC of the P+1th row are connected to the second ports **2** of the ConSource V**1**/V**2**/V**3** modules **108** of the Qth row of system **2750″** '. The first, second and third output terminals A**4**, B**4** and C**4** of motor **2200‴** are connected to the first ports **1** of the ConSource V**1**/V**2**/V**3** modules of the first row of the system **2750′**. The second ports **2** of the ConSource V**1**/V**2**/V**3** modules **108**-1 of the first row are connected any number of intervening rows (not shown) in cascaded fashion as described herein, up to the first ports of the Qth row of all three array columns of system **2750′**.

(172) The third and fourth ports **3** and **4** of the six IC modules **108**-IC of the N+1th row of system **2750** and the P+1th row of system **2750″** are connected together and to first Auxiliary Load **408**. The fifth and sixth ports **5** and **6** of the six IC modules **108**-IC of the N+1th row of system **2750** and the P+1th row of system **2750″** are connected together and to second Auxiliary Load **410**. Auxiliary Loads **408** and **410** have different voltages and represent, for example, but not limited to, an electric vehicle's onboard network system and air-conditioner power supply system, respectively. The configuration of FIG. **27**B can be used in multiple stationary and mobile applications, including four wheel EV's having four in-wheel motors **2200**, **2200′**, **2200″**, **2200‴**, to provide all wheel drive. This embodiment can be configured such that motors **2200** and **2200″** are the front wheel motors, and motors **2200′** and **2200′** are the rear wheel motors, or the reverse. Regardless of whether Auxiliary Loads **408** and **410** are supplied, this embodiment permits inter-phase balancing between phases within each individual system and across the four systems (e.g., inter-system or inter-pack balancing).

(173) FIG. **28** shows an example embodiment of a seventh version of a ConSource pack including a plurality of ConSource modules **108**, connected in three-dimensional array, connected to three-phase open-winding electrical motor **2850** and auxiliary loads **408**, **410** according to the present disclosure. In this embodiment, the modules **108** can be segmented into a first system **2800** and a second system **2800′**. Both systems **2800** and **2800′** can operate with similar frequency but different voltages. All of the modules **108** shown here can, if desired, be combined in a single energy pack, where the modules **108** are co-located in a single common enclosure or housing. Alternatively, the modules **108** of system **2800** can be combined in a first pack, and the modules **108** of system **2800′** can be combined in a different, second pack.

(174) The first ports **1** of ConSource V**1**/V**2**/V**3** modules **108** of the first rows of all three array columns **2810** are connected together. The second ports **2** of the ConSource V**1**/V**2**/V**3** modules of the first rows of all three array columns are connected to the first ports **1** of ConSource V**1**/V**2**/V**3** modules (not shown) of the second rows of all three array columns **2810**, and so on in the same order further down to the Nth row of each array column. The second ports **2** of ConSource V**1**/V**2**/V**3** modules **108** of the Nth rows of all three array columns are connected to the first, second and third terminals A, B, C of the open-winding electrical motor **2850**, as shown in FIG. **28**. The first, second and third terminals A′, B′, C′ of the open-winding electrical motor **2850** are

connected to the first ports **1** of ConSource V**1**/V**2**/V**3** modules of the N+1th rows of all three array columns. The second ports **2** of the ConSource V**1**/V**2**/V**3** modules of the N+1th rows of all three array columns are connected to the first ports **1** of ConSource V**1**/V**2**/V**3** modules of the N+2th rows of all three array columns, and so on in the same order further down to Mth row of each of the array columns. The second port **2** of ConSource V**1**/V**2**/V**3** module of the Mth row of the first column is connected to the first port **1** of a first additional ConSource V**3** module **108**-IC of the M+1th row. The second port **2** of a ConSource V**1**/V**2**/V**3** module of the Mth row of the second array column is connected to the second port **2** of the first additional ConSource V**3** module **108**-IC of the M+1th row. The second port **2** of a ConSource V**1**/V**2**/V**3** module of the Mth row of the third column is connected to the first port **1** of a second additional ConSource V**3** module **108**-IC of the M+1th row.

(175) The third and fourth ports **3** and **4** of the two additional ConSource V**3** modules of the M+1th rows are connected together and to a second Auxiliary Load **410**. The fifth and sixth ports **5** and **6** of the two additional ConSource V**3** modules of the M+1th rows are connected together and to a first Auxiliary Load **408**. The first Auxiliary Load and the second Auxiliary Load have different voltages and represent, for example, but not limited to, electric vehicle's onboard network system and air-conditioner power supply system, respectively.

(176) In addition to the advantages mentioned with regard to FIG. **22**, this three-phase motor drive embodiment of system **100** (three-dimensional array) shown in FIG. **28**, with two additional interconnection ConSource V**3** modules, is suitable for open winding motors and enables an effective and fast exchange of energy between all ConSource modules of the system (inter-phase balancing) and phases electric motor. The additional output terminals **3**, **4**, **5**, **6** of interconnection ConSource V**3** modules provide low voltages of different levels, which can be used to provide power for auxiliary loads, which in turn represent, for example, the electrical on-board network and HVAC power line of an electric vehicle. In this case an extra low-voltage battery is not required; the energy for above mentioned systems is delivered by entire array of ConSource modules. In the embodiment of FIG. **28**, all modules can be implemented in a single pack, or the modules of rows **1** through N can be implemented as a first pack, and the modules of rows N+1 through M (or M+1) can be implemented as a second pack.

(177) FIG. **29** shows an example embodiment of a eighth version of a ConSource pack including a plurality of ConSource modules **108** connected in a three-dimensional array and forming two systems **2901** and **2901**, connected to two three-phase open-winding electrical motors **2850**, **2850′** and auxiliary loads **408, 410** according to the present disclosure. More particularly, two three-phase sub-systems **2900, 2900′** are used to drive motor **2850** and supply auxiliary loads **408** and **410**, while two other three-phase sub-systems **2900″, 2900‴** are used to drive motor and **2850′**, and both systems **2901** and **2902** are interconnected with modules **108**-IC of sub-system **2900′**. Therefore system **2901** and system **2902** may operate in different voltages and frequencies while within system **2901**, sub-system **2900** and **2900′** may operate at similar or equal frequency but may have different voltages, and within system **2902**, sub-system **2900″** and **2900‴** may operate at similar or equal frequency but may have different voltages. All of the modules **108** shown in FIG. **29** can be combined in a single pack. Alternatively, all of the modules **108** of system **2901** can be combined in a single pack, and all of the modules **108** of system **2902** can be combined in a different, second pack. In yet another embodiment, the modules **108** of each of the four sub-systems **2900, 2900′, 2900″, 2900′** are combined in four separate packs **2705, 2705′, 2705″, 2705′** respectively. Combinations of these different pack configurations for systems **2901** and **2902** can also be implemented. In some embodiments the IC modules **108**-IC can be individually or together combined in a separate and independent pack.

(178) The first ports **1** of ConSource V**1**/V**2**/V**3** modules **108-1** of the first rows of all three array columns are connected together. The second ports **2** of the ConSource V**1**/V**2**/V**3** modules **108** of the first rows of all three array columns are connected to the first ports **1** of ConSource V**1**/V**2**/V**3**

modules **108-1** (not shown) of the second rows of all three array columns, and so on in the same order further down to an Nth row. The second ports **2** of ConSource V**1**/V**2**/V**3** modules **108**-N of the Nth rows of all three array columns are connected to the first, second and third terminals A**1**, B**1**, C**1** of a first open-winding electrical motor **2850**, as shown in FIG. **29**. The first, second and third terminals A**1**′, B**1**′, C**1**′ of the first open-winding electrical motor **2850** are connected to the first ports **1** of ConSource V**1**/V**2**/V**3** modules **108**-(N+1) of the N+1th rows of all three array columns. The second ports **2** of the ConSource V**1**/V**2**/V**3** modules **108**-(N+1) of the N+1th rows of all three array columns are connected to the first ports **1** of ConSource V**1**/V**2**/V**3** modules of the N+2th rows (not shown) of all three array columns, and so on in the same order further down to an Mth row.

(179) The second ports **2** of ConSource V**1**/V**2**/V**3** modules **108**-M of the Mth rows of all three array columns of the ConSource pack are connected to the first ports **1** of three corresponding ConSource V**3** modules **108**-IC of the M+1th row, as shown in FIG. **29**. The second ports **2** of all three ConSource V**3** modules **108**-IC of the M+1th row are connected to the second ports **2** of ConSource V**1**/V**2**/V**3** modules **108**-(M+2) of the M+2th row. The first ports **1** of ConSource V**1**/V**2**/V**3** modules of the M+2th row are connected to the second ports **2** of ConSource V**1**/V**2**/V**3** modules of the M+3th row (not shown), and so on in the same order further down to a Kth row. The first ports **1** of ConSource V**1**/V**2**/V**3** modules **108**-K of the Kth rows of all three array columns are connected to the first, second and third input terminals A**2**, B**2**, C**2** of a second open-winding electrical motor **2850**′, as shown in FIG. **29**.

(180) The first, second and third output terminals A**2**′, B**2**′, C**2**′ of the second open-winding electrical motor **2850**′ are connected to the first ports **1** of ConSource V**1**/V**2**/V**3** modules **108**-(K+1) of the K+1th rows of all three array columns. The first ports **1** of ConSource V**1**/V**2**/V**3** modules of the K+1th rows of all three array columns are connected to the second ports **2** of ConSource V**1**/V**2**/V**3** modules of the K+2th rows (not shown) of all three array columns, and so on in the same order further down to an Lth row. The first ports **1** of ConSource V**1**/V**2**/V**3** modules the Lth of rows of all three array columns are connected together.

(181) The third and fourth ports **3** and **4** of the two additional ConSource V**3** modules of the M+1th rows are connected together and to a second Auxiliary Load **410**. The fifth and sixth ports **5** and **6** of the two additional ConSource V**3** modules of the M+1 rows are connected together and to a first Auxiliary Load **408**. The first Auxiliary Load and the second Auxiliary Load **410** have different voltages and represent, for example, but not limited to, electric vehicle's onboard network system and air-conditioner power supply system, respectively.

(182) This three-dimensional array embodiment of system **100** with three additional interconnection ConSource V**3** modules shown in FIG. **29**, provides the independent voltage and frequency regulation (control) for two independent open-winding motors (dual-motor drive system) and allows an effective and fast exchange of energy (inter-phase balancing) between all ConSource modules of such a dual-motor system and phases of two electric motors. The additional output terminals **3**, **4**, **5**, **6** of interconnection ConSource V**3** modules provide low voltages of different levels, which can be used to provide power for auxiliary loads, which in turn represent, for example, the electrical on-board network and HVAC power line of an electric vehicle. In this case an extra low-voltage battery is not required; the energy for above mentioned systems is delivered by entire array of ConSource modules.

Example Embodiments of Module Control

(183) Turning to FIGS. **30-40**B, example systems and methods that facilitate control of system **100** to provide balancing between ConSource modules in different system configurations are shown. The architecture of the example embodiments shown in FIGS. **1** through **29** enables the control of power sharing among ConSource modules. Such control enables maintaining one or more parameters, such as the SOC of the energy sources of the ConSource modules, balanced during discharging, charging, and at rest which can help the full capacity of each energy source to be

utilized regardless of possible differences in the capacities. In addition, balancing can be used to equalize the temperature of the energy sources and/or other components of ConSource modules. Temperature balancing increases the power capability of system **100** and provides more uniform aging of the energy sources regardless of their location within system **100** and differences in thermal resistivity.

(184) System **100** can balance parameters of modules **108** within a particular phase, which can be referred to as intra-phase balancing, and can balance parameters of modules **108** in different phases or a multi-phase (e.g., two or more phase) system, which can be referred to as inter-phase balancing. The control circuitry **102** for system **100** can simultaneously perform any combination of intra-phase balancing, inter-phase balancing, utilization of multiple energy sources within a module (FIG. **11**), active filtering (FIGS. **12**A-**12**B), and auxiliary load supply (FIG. **13**).

(185) FIG. **30** depicts an example embodiment of a single-phase AC or DC balancing controller **3000** that may include a peak detector **3010** ("Peak Detection"), a divider **3020** ("Division"), and an Intra-phase balancing controller **3030** ("Intra-phase Balancing Controller"). The peak detector **3010** detects the peak Vpk of the reference voltage Vr, which can be specific to the phase controller **3000** is operating with and/or balancing. The divider generates normalized reference waveform Vrn by dividing the reference voltage Vr by its detected peak Vpk. Intra-phase balancing controller **3030** uses peak voltage Vpk along with the ConSource status information (e.g., SOCi, Ti, Qi, Vi, etc.) to generate modulation indexes Mi for each module within the phase being controlled. The single-phase balancing controller **3000** can be implemented in hardware, software or a combination thereof, and may be located as a part of the MCD, or may be distributed partially or fully among the LCDs described herein, or may be a separate controller independent of the MCD and LCDs.

(186) In the single-phase AC or DC case, or with respect to a single phase of a multi-phase system, the single-phase balancing controller **3000** (e.g., as a part of the MCD) receives the reference voltage Vr and collects status information such as state of charge SOCi, temperature Ti, capacity Qi, and voltage Vi from all ConSources of system **100** (e.g., from the LCDs of the system). Controller **3000** uses these signals to generate Modulation indexes Mi and a normalized reference waveform Vrn which is then sent to each LCD to generate switching signals. The reference waveform Vrn can be sent continually, and the modulation index can be sent at regular intervals, such as once for every period of the Vrn. The LCD can modulate or scale the normalized reference Vrn by the received modulation index. The modulation index, in some examples, can be a number between zero and one (inclusive of zero and one). This modulated or scaled Vrn can be used as Vref (or −Vref) according to the pulse width modulation technique described with respect to FIGS. **14**A-**14**D, or according to other modulation techniques. In this manner, the modulation index can be used to control the PWM switching signals generated by the LCD and provided to the converter switching circuitry (e.g., S**3**-S**6** or S**1**-S**6**), and thus regulate the operation of each ConSource module. For example, a ConSource module being controlled to maintain normal or full operation may receive a modulation index of one, while a ConSource module that is being controlled to less than normal or full operation may receive a modulation index less than one. A ConSource module that is controlled to cease power output may receive a modulation index of zero. Those of ordinary skill in the art will readily recognize, after reading the present description, that other values of the modulation index can be used to achieve similar functionality.

(187) Single-phase balancing controller **3000** can generate a modulation index for each ConSource module according to any number of aspects or operating characteristics described herein, such as its energy source's state of charge (SOC), temperature (T), capacity (Q), state of health (SOH), voltage (V) and/or current (I) in a manner that facilitates the following: the sum of the generated ConSource voltages does not exceed the peak voltage Vpk. For example, Vpk can be the sum of the products of each module's primary energy source voltage and the modulation index for that module (e.g., Vpk=M.sub.1V.sub.1+M.sub.2V.sub.2+M.sub.3V.sub.3 . . . +M.sub.N V.sub.N, etc). A different combination of modulation indexes, and thus respective voltage contributions by the

modules, may be used but the total generated voltage should remain the same. FIG. **31** is a phasor diagram depicting the peak voltage **3100** required for output by a single phase array, alongside a first example of an output voltage **3100′** produced across two opposite terminals A, B of a four module array, where output voltage **3100′** is a superposition of four equal voltage contributions from each of the four modules. Also shown is a second example of an output voltage **3100″** where the relative contributions of the four modules are adjusted and unequal.

(188) Further, controller **3000** can control operation, to the extent it does not prevent achieving the power output requirements of the system at any one time (e.g., such as during maximum acceleration of an EV), such that SOC of the energy source(s) in each module remains balanced or converges to a balanced condition if they are unbalanced, and/or such that temperature of the energy source(s) or other component (e.g., energy buffer) in each module remains balanced or converges to a balanced condition if they are unbalanced. Power flow in and out of the modules can be regulated such that a capacity difference between sources does not cause an SOC deviation. Balancing of SOC and temperature can indirectly cause some balancing of SOH. Voltage and current can be directly balanced if desired, but in many embodiments the main goal of the system is to balance SOC and temperature, and balancing of SOC can lead to balance of voltage and current in a highly symmetric systems where modules are of similar capacity and impedance.

(189) Since balancing all parameters may not be possible at the same time (e.g., balancing of one parameter may further unbalance another parameter), a combination of balancing any two or more parameters (SOC, T, Q, SOH, V, I) may be applied with priority given to either one depending on the requirements of the application. Priority in balancing can be given to SOC over other parameters (T, Q, SOH, V, I), with exceptions made if one of the other parameters (T, Q, SOH, V, I) reaches a severe unbalanced condition outside a threshold.

(190) As mentioned, balancing can also be performed in an inter-array or inter-phase manner. For ease of description the embodiments will be described with respect to inter-phase balancing. In all the embodiments described herein, inter-phase balancing can be performed at the same time as intra-phase balancing is being performed. For example, FIG. **32** depicts an example embodiment of a three-phase balancing controller **3200**, which can include one inter-phase controller **3210** and three intra-phase balancing controllers **3220-1**, **3220-2**, **3220-3** for phases A, B, and C, respectively. The intra-phase balancing controllers **3220** can be configured or programmed to balance aspects of the ConSource modules within each one-dimensional array, in particular and as an example, within one-phase. The inter-phase balancing controller **3210** can be configured or programmed to balance aspects of the ConSource modules among or across the entire multi-dimensional array, in particular and as an example, among or across arrays of different phases. This may be achieved through injecting common mode to the phases (e.g., neutral point shifting) or through interconnection modules (common modules) or through both. Controller **3200** can be implemented in hardware, software or a combination thereof, and may be located as a part of the MCD, or may be distributed partially or fully among the LCDs described herein, or may be a separate controller independent of the MCD and LCDs. The intra-phase balancing controllers **3220-1**, **3220-2**, **3220-3** and inter-phase balancing controller **3210** can each individually be implemented in hardware, software or a combination thereof, and may be located as a part of the MCD, or may be distributed partially or fully among the LCDs described herein, or may be a separate controller independent of the MCD and LCDs.

(191) The reference signal input to this system may be VrA, VrB, VrC or any combination of two of these signals or any other transformation that can recreate these signals such as Clarke transform (i.e., Vrα, Vrβ).

(192) FIGS. **33**A and **33**B are phasor diagrams depicting example embodiments **3300** and **3300′** of control techniques for a Y-connected three-phase system without interconnection (IC) modules between phases A, B, and C (see, e.g., system **100** as described with respect to FIGS. **18** and **22**). Here, intra-phase balancing can be performed or achieved by controlling the modulation indexes of

the modules within each phase A, B, and C, where each double-sided arrow indicates the energy contribution of a particular module within each phase in an example having nine modules with three in each phase).

(193) Inter-phase balancing can be performed by the control circuitry (e.g., controller **3200**, MCD **112**) by adding certain common modes to the phase references (VrnA, VrnB, VrnC), the neutral point 'N' may be shifted from one position to another. A change in a phase reference causes a change in modulation indexes of all the modules in that phase which increases or decreases their aggregated contribution to the power. For example, after measuring one or more parameters (e.g., SOC, T, Q, SOH, V, I) of the modules in each phase, inter-phase balancing controller **3210** can determine to adjust the energy output (discharging) or input (charging) to one or more phases. For example, if a determination is made to lower the energy output of the modules in phase A by 10%, then a component equal to 10% of VrnA can be subtracted from VrnA, and this same 10% component (e.g., the common mode) of VrnA can also be subtracted from VrnB and VrnC, which will shift the neutral point towards A. As mentioned above, this can occur at the same time as intra-phase balancing is being performed.

(194) For example in FIG. **33**B, assuming that the system is discharging and the total energy available in the modules of phase A is smaller than the total energy available in modules of phase C, which in turn is smaller than the total energy available in modules of phase B, for SOC balancing the neutral point can be shifted from the position of FIG. **33**A to that of FIG. **33**B, as shown by **3310**, according to a similar common mode technique. This decreases the contribution of phase A, and to a lesser extent decreases the contribution of phase C, and increases the contribution of phase B to compensate. This provides control over the share of energy output by each phase to establish the three phase voltages.

(195) FIGS. **34**A and **34**B are phasor diagrams depicting example embodiments **3400** and **3400′** of control techniques for a Y-connected three-phase system with interconnection (IC) modules between phases A, B, and C (see, e.g., system **100**, FIGS. **20** and **24**). Here, intra-phase balancing can again be achieved by controlling the modulation indexes of the modules within each phase array as described. Inter-phase balancing, e.g., controlled overall by controller **3200**, can be performed by selectively applying energy from one or more IC modules to the arrays of one or more phases, which can be referred to as inter-phase energy injection. This is depicted in FIG. **34**A, where a fourth contribution (as compared to the example of FIG. **33**A) supplied by the IC module(s) has been added in the center of the phasor diagram.

(196) FIG. **34**A represents an example where the system is discharging and the total energy (SOC) available in the three modules of phase A is smaller than the total energy available in the three modules of phase C, which in turn is smaller than the total energy available in the three modules of phase B (SOC.sub.A<SOC.sub.C<SOC.sub.B). Controller **3200** can supply or output a modulation index to the IC module of phase A that is greater than the modulation index for the IC module of phase B (which can be the same or a different IC module), that in turn is greater than the modulation index for the IC module of phase C (which can be the same or a different IC module than that of A and B) (M.sub.IA>M.sub.IC>M.sub.IB). The modulation indexes for the non-interconnection modules within each phase can be decreased accordingly, and therefore the contribution of non-interconnection modules of phase B is more than those of phase C, which in turn is more than those of phase A, which moves the system toward balanced SOC in all phases. A similar approach can be used to balance one or more of the other parameters (T, Q, SOH, V, I).

(197) In systems with IC modules between phases, inter-phase balancing can also be performed by neutral point shifting (or common mode injection) as described above. FIG. **34**B depicts an example where inter-phase balancing is performed by controller **3200** in a system with IC modules using both common mode injection and inter-phase energy injection. Such a combination allows for more robust and flexible balancing under a wider range of operating conditions.

(198) System **100** can determine the appropriate circumstances under which to perform inter-phase

balancing with neutral point shifting alone, inter-phase energy injection alone, or a combination of both simultaneously. Neutral point shifting can be performed with energy from all of the modules of each phase array, whereas inter-phase energy injection is performed with energy from just the one or more IC modules. Thus neutral point shifting has a wider range of energy available to cover more disparate inter-phase imbalances. There may be embodiments where system **100** is supplying auxiliary loads or other systems where shifting the neutral point is undesirable, and in some cases neutral point shifting may increase the phase shift between voltage and current of the phase array, which may increase DC second order harmonics. Inter-phase energy injection permits balancing without shifting the neutral point and can avoid these potential side effects. In some embodiments, control circuitry **102** (e.g., controller **3200**, MCD **114**) can use inter-phase energy injection for inter-phase imbalances that are relative small or minor, and can use neutral point shifting (either alone or with inter-phase energy injection) for inter-phase imbalances that are relatively larger or more severe, and/or that require balancing in a short period of time. In these embodiments, control circuitry **102** can be configured to assess or determine the degree of inter-phase imbalance and compare it to a threshold (e.g., SOC, temperature) that differentiates between the inter-phase imbalances that are relatively small and relatively large (or other condition that governs which technique to use), and execute inter-phase balancing using only inter-phase energy injection for small differences and using either neutral point shifting or a combination of both for relatively larger differences.

(199) FIGS. **35**A and **35**B are phasor diagrams depicting example embodiments **3500** and **3500′** of control techniques for a four-phase system without IC modules and with IC modules, respectively, between phases A, B, C, and D. Here, intra-phase balancing can be achieved by controlling the modulation indexes of the modules within each of phases A, B, C, and D. Inter-phase balancing can be achieved by neutral point shifting and/or by controlling the contribution of the interconnection modules to each phase where applicable (inter-phase energy injection).

(200) FIGS. **36**A and **36**B are phasor diagrams depicting example embodiments **3600** and **3600′** of control techniques for a five-phase system without IC modules and with IC modules, respectively, between phases A, B, C, D, and E. Here, intra-phase balancing can be achieved by controlling the modulation indexes of the modules within each of phases A, B, C, D, and E. Inter-phase balancing can be achieved by neutral point shifting and/or by controlling the contribution of the interconnection modules to each phase where applicable (inter-phase energy injection).

(201) FIGS. **37**A and **37**B are phasor diagrams depicting example embodiments **3700** and **3700′** of control techniques for a six-phase system without IC modules and with IC modules (e.g., described with respect to FIG. **26**), respectively, between phases A, B, C, D, E, and F. Here, intra-phase balancing can be achieved by controlling the modulation indexes of the modules within each of phases A, B, C, D, E, and F. Inter-phase balancing can be achieved by neutral point shifting and/or by controlling the contribution of the interconnection modules to each phase where applicable (inter-phase energy injection).

(202) In system **100** as described with respect to FIG. **27**, two three-phase systems **2700** and **2700′** that can discharge and charge with a different voltage and frequency are shown. Intra-phase balancing for these systems can be achieved through controlling the modulation indexes of the modules **108** within each phase A, B, C, A′, B′, C′. Inter-phase balancing within each system **2700** and **2700′** and between the two systems can be achieved by controlling the voltage contribution of the IC modules **108**-IC to each phase. Examples **3810** and **3820** of inter-phase balancing with IC modules **108**-IC is depicted in the phasor diagram of FIG. **38**A, as applied to systems **2700** and **2700′**, respectively, for an example where N is 3. Inter-phase balancing within each system **2700** and **2700′** may alternatively or additionally be accomplished by neutral point shifting as shown in the examples **3810** and **3820** of FIG. **38**B.

(203) In system **100** as described with respect to FIG. **28**, two three-phase systems **2800** and **2800′** are described that discharge with similar frequency but may have different voltage are considered.

Balancing of systems **2800** and **2800′** is described with respect to examples **3900** and **3900′**, respectively, in FIGS. **39**A and **39**B (for an example where N=2 for system **2800** and M-N=3 for system **2800′**). In FIG. **39**A, since complementary phases in the two systems **3900**, **3900′** work in pairs to generate voltage across each motor winding, modules **108** in phase pairs (e.g., A and A′, B and B′, C and C′) may be considered for intra-phase balancing. For example, to establish a certain voltage between A and A′, all the modules **108** in the A and A′ phases can contribute proportionally according to their status information. Inter-phase balancing, or in this case balancing between phase pairs may be implemented through interconnection modules **108**-IC as shown in FIG. **39**A. Inter-phase balancing within each system **2800** and **2800′** may alternatively or additionally be accomplished by neutral point shifting as shown in the examples **3900** and **3900′** of FIG. **39**B. (204) In system **100** as described with respect to FIG. **29**, system **2901** and system **2902** may operate in different voltages and frequencies. Within system **2901**, sub-systems **2900** and **2900′** may operate at similar or equal frequency but may have different voltages, and within system **2902**, sub-systems **2900″** and **2900‴** may operate at similar or equal frequency but may have different voltages. Balancing of systems **2900**, **2900′**, **2900″**, **2900‴** is described with respect to examples **4000**, **4010**, **4020**, **4030**, respectively, in FIGS. **40**A and **40**B (for an example where each system **2900**, **2900′**, **2900″**, and **2900‴** has 3 rows of modules **108** not including IC modules **108**-IC). In FIG. **40**A, since complementary phases in the four systems **4000**, **4010**, **4020**, **4030** work in pairs to generate voltage across each motor winding, modules **108** in phase pairs (e.g., A**1** and A**1**′, B**1** and B**1**′, C**1** and C**1**′, A**2** and A**2**′, B**2** and B**2**′, C**2** and C**2**′,) may be considered for intra-phase balancing. For example, to establish a certain voltage between A**1** and A**1**′, all the modules **108** in the A**1** and A**1**′ phases can contribute proportionally according to their status information. (205) Inter-phase balancing, or in this case balancing between phase pairs may be implemented through interconnection modules **108**-IC of **4010** and **4030** as shown in FIG. **40**A. Inter-phase balancing within each system **2900**, **2900′**, **2900″**, and **2900‴** may alternatively or additionally be accomplished by neutral point shifting as shown in the examples of FIG. **40**B.

Additional Example Embodiments of IC Modules

(206) An interconnection (IC) module can be used for either or both of inter-phase balancing and auxiliary load supply. In addition to being employable as a standard module stage (e.g., one of N modules) within a phase, ConSource module V**3** is shown and described as being employable as an IC module **108**-IC capable of both inter-phase balancing and auxiliary load supply (e.g., see the example embodiments described with respect to FIGS. **4**, **17**, **20**, **21**, **24-29**). IC modules can be implemented in other configurations as well, including those of FIG. **2** and FIG. **3** where the module outputs (out**1** and out**2**) are connected to separate arrays of modules operating in different phases. IC modules can include any number of one or more energy sources, an optional energy buffer, switch circuitry for supplying energy to one or more module arrays and/or for supplying power to one or more auxiliary loads, can include control circuitry (e.g., a local control device), and can include measurement circuitry (e.g., one or more circuits and/or sensors) for measuring various parameters about the IC module itself or its various loads (e.g., SOC of an energy source, temperature of an energy source or energy buffer, capacity of an energy source, SOH of an energy source, voltage and/or current measurements pertaining to the IC module, voltage and/or current measurements pertaining to the auxiliary load(s), etc.).

(207) FIG. **41**A is a block diagram depicting an example embodiment of a system **100** with an IC module **108**-IC configured as for use in inter-phase balancing between arrays **1500**-A, **1500**-B, and **1500**-C of phases A, B, and C, respectively. IC module **108**-IC can be configured according to any of ConSource module embodiments V**1**, V**2**, or V**3**. IC module **108**-IC can selectively connect the one or more energy sources of the module **108**-IC to one or more of the arrays **1500**-A, **1500**-B, and **1500**-C, or to no output. System **100** can be controlled by control circuitry **102** (not shown, see FIG. **1**A). Array **1500**-A outputs an AC voltage waveform (VoutA) at node A, array **1500**-B outputs an AC voltage waveform (VoutB) at node B, and array **1500**-C outputs an AC voltage waveform

(VoutC) and node C.

(208) FIG. **41**B is a schematic diagram depicting an example embodiment of IC module **108**-IC having Energy Source **202** coupled with switch circuitry **132**. As described with respect to switch circuitry **207** and **208**, switch circuitry **132** can be configured in any arrangement and with any switch types (e.g., MOSFET, IGBT, Silicon, GaN, etc.) suitable for the requirements of the application. Switch circuitry **132** has an output **133**-1, **133**-2, and **133**-3 coupled to a module of each of arrays **1500**-A, **1500**-B, and **1500**-C. In other embodiments, IC module **108**-IC can be coupled with a system having only two phases, in which case only two outputs **133** are necessary. Similarly, IC module **108**-IC can be scaled up with additional switch circuitry and outputs to couple to systems having more than three phases.

(209) With reference to FIGS. **41**A and **41**B, the three arrays **1500** are located electrically between IC module **108**-IC and the outputs A, B, C to the load. Put differently, array **1500**-A has a first terminal A for connection to a load and a second terminal (located opposite to the first terminal on the opposite end of array **1500**-A) for connection to output **133**-1 of IC module **108**-IC. Similarly, array **1500**-B and array **1500**-C each have a first terminal B and C, respectively, for connection to the load, and a second terminal for connection to outputs **133**-2 and **133**-3, respectively, of IC module **108**-IC. Positioning of IC module **108**-IC in this manner allows, among other things, the IC module to control the routing of current between each of the three phase arrays **1500**-A, B, and C.

(210) In this embodiment, switch circuitry **132** is implemented with three switch sections **134**-1, **134**-2, and **134**-3, each coupled to a respective output **133**. Each switch section **134** can be controlled by control circuitry (e.g., control circuitry **102**, see FIG. **1**A) via one or more control input lines **136**. The control circuitry can control switch circuitry **132** according to any desired control technique, including the PWM and hysteresis techniques mentioned herein.

(211) In the example of FIG. **41**B, control circuitry **102** is implemented as LCD **114** and MCD **112** (not shown). LCD **114** is associated with this IC module **108**-IC and can receive monitoring data from the IC module **108**-IC (e.g., SOC of ES**1**, temperature of ES**1**, Q of ES**1**, etc.) from sensors or other measurement devices or circuits (not shown) coupled with module **108**-IC. This monitoring data and/or other data derived from this monitoring data can be out to MDC **112** for use in system control as described herein. LCD **114** can also receive timing information (not shown) for purposes of synchronization of modules of the system **100**. One or more carrier signals (not shown), such as the sawtooth signals used in PWM (FIGS. **14**A, **14**B) can also be received by LCD **114** or generated internally by LCD **114**.

(212) Switch sections **134** can each be implemented as a half leg with switches S**7** and S**8**, selectively controllable by LCD **114** via control input lines **136**-1 through **136**-6. (Switches S**7** and S**8** can be the same as switches S**3** and S**4** (or S**5** and S**6**) described earlier.) For inter-phase balancing, energy from energy source **202** can be supplied to any one or two phase arrays **1500** over time using switch sections **134**. Supply of supplemental energy to one or two phase arrays allows the energy output of those cascaded modules **108**-1 thru **108**-N of those supplied phase arrays to be reduced, relative to the unsupplied phase array(s).

(213) For example, in some example embodiments applying PWM, LCD **114** can be configured to receive the normalized voltage reference signal (Vrn) (from MCD **112**) for each of the one or more phase arrays that IC module **108**-IC is coupled to, which in this example is all three: VrnA, VrnB, VrnC. LCD **114** can also receive modulation indexes MiA, MiB, MiC for the switch sections **134**-1, **134**-2, **134**-3 for each phase array, respectively, from MCD **112**. LCD **114** can modulate (e.g., multiply) each respective Vrn with the modulation index for the switch section coupled directly to that phase array (e.g., VrnA multiplied by MiA) and then utilize a carrier signal to generate the control signal(s) for each switch section **134**. In other embodiments, MCD **112** can perform the modulation and output modulated voltage reference waveforms for each section **134** directly to LCD **114**. In still other embodiments, all processing and modulation can occur by a single control entity that can output the control signals directly to each section **134**.

(214) This switching can be modulated such that power from Energy Source **202** is supplied to the array(s) at appropriate intervals and durations. Such methodology can be implemented in various ways.

(215) In one example embodiment, the PWM approach described with respect to FIGS. **14**A-**14**D is applied to the embodiment of FIGS. **41**A and **41**B, where the switch circuitry **207** of each module **108**-1 through **108**-N is configured as an H-bridge (FIG. **5**A). For an example case where there are four cascaded stages (N=4) in each array **1500**, plus an IC module **108**-IC, then nine carrier signals (2N+1) equally offset in phase angle are used to generate control signals. Eight of the nine carrier signals are used to generate control signals for each of the four modules **108**-1 through **108**-4 (e.g., one carrier for S**3** and S**4** and one carrier for S**5** and S**6** per module) of a particular array **1500**, and the ninth carrier can be used to generate the control signals for the switch section **134** of the IC module **108**-IC. Each AC output waveform (Vout) can thus be an eleven level waveform with a first level at zero volts, eight levels producible by the four cascaded modules **108**-1 through **108**-4, and two producible by IC module **108**-IC (+Vic and −Vic shown in FIG. **41**B). (Energy Source **202** of IC module **108**-IC is preferably the same standard voltage as the energy sources of the cascaded modules, although such is not required.)

(216) During balanced operation, the modulation index for each switch section **134** can be set at a value that causes the same or similar amount of net energy to be supplied by energy source **202** and/or energy buffer **204** to each array **1500**. For example, the modulation index used for each switch section **134** could be the same or similar, and can be set at a level or value that causes the IC module(s) to perform a net or time average discharge of energy to one or more arrays **1500** during balanced operation, so as to drain the IC module(s) at the same rate as other modules in the system. In some embodiments, the modulation index used for each switch section **134** could be the same or similar, and can be set at a level or value that does not cause a net or time average discharge of energy during balanced operation (causes a net energy discharge of zero). This can be useful in a situation where the IC module(s) may be drained below the level of the other modules and continued operation of the other modules is required without draining the IC module(s) in order to reach similar SOC levels across the entire system **100**. For example, this could occur if an EV is supplying power to the auxiliary loads for an extended period of time without driving.

(217) When an unbalanced condition occurs between arrays **1500**, then the modulation indexes of system **100** can be adjusted to cause the system to converge back to a balanced condition. For example, control circuitry **102** can detect that one of arrays **1500** has a relatively lower SOC parameter (e.g., sum total SOC of cascaded modules **108**-1 to **108**-4) than the other arrays. Control circuitry **102** can then cause the IC module **108**-IC to discharge more to that low array than the others, and can also cause the cascaded modules of that low array to discharge relatively less (e.g., on a time average basis). The relative net energy contributed by the IC module **108**-IC increases as compared to the modules of the array being assisted, and also as compared to the amount of net energy the IC module contributes to the other arrays. This can be accomplished by increasing the modulation index for the IC module switch section supplying that low array, and by decreasing the modulation indexes of one or more cascaded modules of that low array, in a manner that maintains Vout for that low array at the appropriate or required levels, and leaving the modulation indexes for other switch sections **134** supplying the other phase arrays relatively unchanged. Additional example embodiments of inter-phase balancing with IC modules are described with respect to FIGS. **42**A-**42**B below.

(218) IC module **108**-IC can also be scaled to supply current to one or more phases of a first system or pack, and one or more phases of a second system or pack (see e.g., IC modules **108**-IC of FIGS. **27**A, **27**B, and **29**). For example, a first switch section **134**-1 of an IC module can be coupled with a phase array of a first pack, and a second switch section **134**-2 of the IC module can be coupled with a phase array of a different second pack. The first pack can have multiple arrays providing multi-phase supply to a first motor and the second pack can have multiple arrays providing multi-

phase supply to a second motor (e.g., as depicted in FIGS. **27**A, **27**B and **29**). For inter-pack balancing, energy from the IC module can be supplied to the two phase arrays of the different packs over time using switch sections **134-1** and **134-2**. The system can be scaled such that each IC module supplies two arrays, one from each pack, thus requiring three IC modules for two three phase packs (as shown in FIGS. **27**A, **27**B, and **29**), or each IC module supplies more than two arrays, up to and including all arrays of both packs (e.g., one IC module coupled all three arrays of a first three-phase pack and all three arrays of a second three phase pack). The control circuitry can monitor relative parameters (e.g., SOC and temperature) of the arrays of the different packs and adjust the energy output of the IC modules to compensate for imbalances between arrays or phases of different packs in the same manner described herein as compensating for imbalances between arrays or phases of the same pack. In all cases with multiple IC modules, the energy sources can be coupled together in parallel so as to share energy as described herein.

(219) IC module **108**-IC can also be configured to supply power to one or more Auxiliary Loads **408** (at the same voltage as Energy Source **202**) and/or one or more Auxiliary Loads **410** (at voltages stepped down from Energy Source **202**). FIG. **41**C is a block diagram depicting an example embodiment of a system **100** similar to that of FIG. **41**A, but with IC module **108**-IC supplying auxiliary loads **408**, **410-1**, and **410-2**. FIG. **41**D is a schematic and block diagram depicting this example embodiment of system **100** with emphasis on IC module **108**-IC having energy source **202** coupled with switch circuitry **132**. Here, control circuitry **102** is again implemented as LCD **114** and MCD **112** (not shown). LCD **114** can receive monitoring data from IC module **108**-IC (e.g., SOC of ES**1**, temperature of ES**1**, Q of ES**1**, voltage of Aux Loads **410**, etc.) and can output this and/or other monitoring data to MDC **112** for use in system control as described herein. In this embodiment, switch circuitry **132** is configured to provide inter-phase balance capability and also to supply Auxiliary loads **408**, **410-1**, and **410-2**. Switch circuitry **132** is implemented with two additional switch sections **208-1** and **208-2**, which can have numerous different configurations. Here, sections **208-1** and **208-2** each include switches S**1** and S**2**, and thus are configured like the embodiment described with respect to FIG. **5**B. Switch section **208-1** has an output coupled to inductor L.sub.C1, which is in turn coupled with Auxiliary Load **410-1**. Switch section **208-2** has an output coupled to inductor L.sub.C2, which is in turn coupled with Auxiliary Load **410-2**. Switch sections **208-1** and **208-2** can be controlled by LCD **112** with one or more control lines **136**.

(220) Auxiliary Loads **410-1** and **410-2** can operate at different voltages based on the inductance of L.sub.C1 and L.sub.C2 and the duty cycles applied to switch sections **208-1** and **208-2**. For example, if Energy Source **202** operates at 48V, then Auxiliary Load **408** can also operate at 48V, Auxiliary Load **410-1** can operate at 24V, and Auxiliary Load **410-2** can operate at 12V. Those of ordinary skill in the art will recognize from this disclosure that the embodiments can be operated at almost limitless different voltages and combinations of voltages. Voltage and/or current monitoring circuitry (not shown) can monitor the voltage and/or current supplied to Auxiliary Loads **410-1** and **410-2**, which is then fed back to LCD **114** as monitoring data from the module. This data can be used by LCD **114** to control the duty cycle of switch sections **208-1** and **208-2** and thus independently regulate the voltages supplied to loads **410-1** and **410-2**.

(221) In order to increase the power supply capability of IC module **108**-IC, Energy Source **202** can be configured with a higher capacity than the energy sources of modules **108**. For example, in an embodiment where one IC module applies energy to three phase arrays, and the energy output by the IC module for each phase array is approximately one half that of the modules in that phase array, then the IC module preferably has a capacity 1.5 times greater than the modules in the phase arrays (assuming those modules have the same capacity), so as to allow the IC module to discharge at the same rate as the modules of the phase arrays themselves. If the IC module is also supplying an auxiliary load, then an even greater capacity may be desired, such as twice the capacity of the modules in the phase arrays, so as to permit the IC module to both supply the auxiliary load and

discharge at relatively the same rate as the other modules. Alternatively, or in addition to a higher capacity, IC modules **108**-IC can be connected such that the Energy Sources **202** of more than one, or all, of the IC modules **108**-IC are in parallel as described and shown herein with respect to ConSource module V**3** **108**-IC (see, e.g., coupling together of ports **3** and **4** as described with respect to FIGS. **4**, **20**, **21**, and **24-29**). In those examples, placing the energy sources in parallel essentially doubles the capacity and permits the IC modules to discharge at relatively the same rate as the other modules in the system while also supplying the auxiliary loads.

(222) FIG. **41**E is a block diagram depicting an example embodiment of a system **100** similar to that of FIG. **25**, but without showing the load or motor. Here, two IC modules **108**-IC-**1** and **108**-IC-**2** are implemented, with module **108**-IC-**1** coupled with phase arrays **1500**-A and **1500**-B, and with module **108**-IC-**2** coupled with phase array **1550**-C. Both modules **108**-IC supply auxiliary loads **408** and **410**. FIG. **41**F is a schematic diagram of the system of FIG. **41**E with emphasis on the two IC modules **108**-IC and their LCDs **114**, with module **108**-IC-**1** implemented as ConSource V**3** module **108**-IC and module **108**-IC-**2** implemented as a ConSource V**3** module **108**-IC but without the second switch section **134** (e.g., switches S**5** and S**6** of FIG. **5**B). Here each module **108**-IC-**1** and **108**-IC-**2** includes switch circuitry **208** and a coupling inductor LC to supply Auxiliary Load **410** so as to double the current carrying capacity.

(223) The use of two or more IC modules **108**-IC with energy sources **202** connected in parallel, as shown here via connections to nodes **3** and **4** of each module, enables energy to be exchanged between modules, and enables both to operate while staying in a relatively balanced condition. In other words, the energy source **202** of IC module **108**-IC-**1** will stay at the same or similar charge level as the energy source **202′** in the second IC module **108**-IC-**2**. As the currents in each phase change polarity, each energy source **202** can potentially be continuously charged by current incoming from one or more of the phases operating with a negative polarity at that time. In configurations with multiple IC modules, the energy sources **202** of each IC module **108** preferably have the same capacity, although that is not required, and in some embodiments the IC modules can have different capacities. Similarly, the energy sources **202** of the IC modules can have the same capacity as the cascaded modules in each array, so that discharge rates are generally the same. But in other embodiments can have different capacities. Also, in other embodiments the energy sources of multiple IC modules **108**-IC can be coupled in series instead of parallel.

Additional Example Embodiments of Inter-Phase Balancing with IC Modules

(224) FIGS. **42**A-**42**B are flow diagram depicting example embodiments of methods of performing inter-phase balancing in a system **100** having at least one IC module **108**-IC. The system can have any configuration or topological arrangement of modules **108** described herein, or others, and can supply (or store) energy for or from any number of two or more phases. The arrays being balanced can be supplying the same load or motor, or can be in different systems or packs supplying different loads or motors (e.g., inter-system or inter-pack balancing). Because the switching circuitry of all modules tends to operate at a relatively high frequency in accordance with PWM and hysteresis techniques, the references to energy outputs by the modules (e.g., increasing, decreasing, or staying the same) is across time, e.g., on a time average or net basis. These references to energy outputs can also be expressed as cumulative or aggregate energy over time (e.g., over multiple consecutive periods of the output waveforms).

(225) FIG. **42**A shows a method **4200**. At **4202**, control circuitry **102** can determine or assess whether an unbalanced condition exists between at least two different arrays **1500** that is sufficient to invoke inter-phase balancing. This determination can be based on a broad range of one, two or more types of qualitative or quantitative information (e.g., measurements or characterizations) communicated to the control circuitry (e.g., collected by LCDs and communicated to the MCD). The following paragraphs describe a few non-limiting examples of these various types applicable to all embodiments described herein.

(226) The unbalanced condition can relate to energy or charge in the arrays, such as an SOC

parameter (e.g., measurement) of or characterizing one array being less than, more than, or substantially different than the SOC value for at least one different array or the system as a whole. The SOC parameter can be, e.g., total SOC of all modules in an array, central tendency value (e.g., average or median) of SOC of all modules in an array, SOC of one or more modules in the array, a rate of change of SOC in one or more modules in the array, or others.

(227) The unbalanced condition can relate to temperature in the arrays, such as a temperature parameter of or characterizing one array being less than, more than, or substantially different than the temperature parameter for at least one different array or the system as a whole. The temperature parameter can be, e.g., a central tendency value (e.g., average or median) of temperature of all modules in an array, temperature of one or more modules in the array, a rate of change of temperature in one or more modules in the array, or others.

(228) The unbalanced condition can relate to capacity (Q) in the arrays, such as a capacity parameter of or characterizing one array being less than, more than, or substantially different than the Q parameter for at least one different array or the system as a whole. The Q parameter can be, e.g., a central tendency value (e.g., average or median) of Q of all modules in an array, Q of one or more modules in the array, a rate of change of Q in one or more modules in the array, or others.

(229) The unbalanced condition can relate to State of Health (SOH) in the arrays, such as an SOH parameter of or characterizing one array being less than, more than, or substantially different than the SOH parameter for at least one different array or the system as a whole. The SOH parameter can be, e.g., a central tendency value (e.g., average or median) of SOH of all modules in an array, SOH of one or more modules in the array, a rate of change of SOH in one or more modules in the array, or others.

(230) The unbalanced condition can relate to a voltage in the arrays, such as an voltage parameter of or characterizing one array being less than, more than, or substantially different than the voltage parameter for at least one different array or the system as a whole. The voltage parameter can be, e.g., a central tendency value (e.g., average or median) of current voltage level of all modules in an array, current voltage of one or more modules in the array, a rate of change of voltage in one or more modules in the array, or others.

(231) The unbalanced condition can relate to a current in the arrays, such as a current parameter of or characterizing one array being less than, more than, or substantially different than the current parameter for at least one different array or the system as a whole. The current parameter can be, e.g., a central tendency value (e.g., average or median) of a present current level of all modules in an array, present current of one or more modules in the array, a rate of change of current in one or more modules in the array, or others.

(232) The unbalanced condition can also be a fault or degradation condition that limits or prevents operation or performance of a module in an array, as such a fault or degradation can lead to an unbalanced condition across all types of measurements and characterizations.

(233) The determination or assessment of whether two arrays are in an unbalanced condition can be relative as described above. The relative difference can be characterized in terms of a comparative fraction or percentile, or in terms of a standardized unit (e.g., Coulomb, degree of temperature, volt, amp, etc.). The system can be configured to invoke inter-phase balancing based on any desired amount or threshold of relative difference, where a smaller relative threshold (e.g., 1%) will invoke inter-phase balancing more frequently than a larger relative threshold (e.g., 5%). The determination or assessment of whether two arrays are in a sufficiently unbalanced condition can be based on an absolute or non-relative value, e.g., an unbalanced condition can be determined to exist if a first array has a value below an absolute threshold (maximum temperature, minimum SOC, etc.), regardless of what value(s) the other array(s) have. The determination of whether two arrays are in an unbalanced condition can be based on both relative and absolute factors, e.g., a temperature of a first array may exceed a relative threshold difference (e.g., 3 degrees Celsius (C) relative difference) as compared to a second array, but inter-phase balancing will not be performed until

both arrays exceed a minimum absolute temperature to commence inter-phase balancing (e.g., 12 degrees C.).

(234) Referring back to FIG. **42**A, if the control circuitry determines that the unbalanced condition requirement is met, then method **4200** proceeds to step **4206** (as indicated by **4204**). If the requirement is not met, then method **4200** reverts to step **4202**. This reversion loop can continue indefinitely while system **100** is operating to continuously or repeatedly monitor for occurrence of the unbalanced condition.

(235) At step **4206**, the control circuitry causes supplemental net energy to be supplied from an energy source of the IC module **108**-IC to the appropriate array **1500** of modules **108**-1 through **108**-N. The appropriate array is the array requiring additional energy to counteract the unbalanced condition. This step can, in some embodiments, include the control circuitry causing a reduction in energy supplied from one or more of the cascaded array of modules **108**-1 through **108**-N, where the reduction is equivalent to the supplemented energy added by the IC module **108**-IC, thus allowing system **100** to meet the load requirements. The control circuitry can determine or estimate the amount of energy output adjustments required to modules **108**-1 through **108**-N and module **108**-IC to cause the arrays to begin converging back to a balanced condition. The amount of supplemental energy can be an incremental amount above the amount (zero or non-zero) supplied by IC module **108**-IC in the balanced operating state occurring prior to step **4206**. Referring back to the example described with respect to FIGS. **41**A-**41**B where N=4, in a sample case where array **1500**-A requires supplementation by IC module **108**-IC, then MCD **112** can determine an amount by which to decrease the modulation index for all of the modules **108**-1 through **108**-4 of array **1500**-A and an amount by which to increase the modulation index for switch section **134**-1, to meet the load requirements and to cause the arrays to converge towards a balanced condition over time. These modulation indexes can be communicated to LCD **114**, which can then modulate VrnA for all of modules **108**-1 through **108**-4 and for switch section **134**-1, and use the modulated waveforms to generate the control signals **136** for each.

(236) After adjusting the relative energy outputs at **4206**, control circuitry can again determine or assess whether the unbalanced condition persists at **4208**. If the condition persists, then the method can revert to step **4206** and the supplemental energy can again be supplied by IC module **108**-IC as described above (as indicated by **4210**). If the unbalanced condition requirement is not met, then method **4200** can proceed to step **4212** where the supplemental supply of energy from IC module **108**-IC can be stopped. This can include a reversion to modulation indexes (for IC module **108**-IC and modules **108**-1 through **108**-4 of **1500**-A) that were in use prior to entering the unbalanced condition, e.g., a reversion to modulation indexes for the balanced condition. Alternatively, this can include a reduction in modulation index for switch section **134**-1 and an increase in the modulation indexes for cascaded modules **108**-1 through **108**-N, to values not necessarily the same as those in use in the prior balanced operation.

(237) FIG. **42**B is a flow diagram depicting another example embodiment of a method **4220** of inter-phase balancing in a system with at least one IC module **108**-IC. Method **4220** is similar to method **4200** except inter-phase balancing is performed by decreasing the energy supplied by the IC module **108**-IC to an array. In this example embodiment, IC module **108**-IC is contributing energy or power to each array **1500** during a balanced condition. Steps **4222** and **4224** are similar to steps **4202** and **4204** of method **4200**. At **4222**, control circuitry **102** can determine or assess whether an unbalanced condition exists between at least two different arrays **1500** that is sufficient to invoke inter-phase balancing. If the unbalanced condition requirement is met, then method **4220** proceeds to step **4226** (as indicated by **4224**). If the requirement is not met, then method **4220** reverts to step **4222**. This reversion loop can continue indefinitely while system **100** is operating to continuously or repeatedly monitor for occurrence of the unbalanced condition.

(238) Instead of using IC module **108**-IC to increase energy output to an array (e.g., having a lower overall SOC), at step **4226**, the control circuitry causes energy output from IC module **108**-IC to

the array having the greater operating margin (e.g., having a higher overall SOC) to be decreased. This step can include the control circuitry causing an increase in the energy supplied from one or more of the cascaded array of modules **108**-1 through **108**-N in the array with the greater margin, where the increase is equivalent to the decremented energy supplied by the IC module **108**-IC to that array, thus allowing system **100** to meet the load requirements. The control circuitry can determine or estimate the amount of energy output adjustments required to the adjusted modules **108**-1 through **108**-N and module **108**-IC to cause the arrays to begin converging back to a balanced condition. Referring back to the example described with respect to FIGS. **41**A-**41**B where N=4, in a sample case where array **1500**-A has a relatively greater overall SOC than array **1500**-B and array **1500**-C, then MCD **112** can determine an amount by which to increase the modulation index for all of the modules **108**-1 through **108**-4 of array **1500**-A and an amount by which to decrease the modulation index for switch section **134**-1 supplying array **1500**-A, to meet the load requirements and to cause arrays **1500**-A to converge towards a balanced condition over time with arrays **1500**-B and **1500**-C. These modulation indexes can be communicated to LCD **114**, which can then modulate VrnA for all of modules **108**-1 through **108**-4 and for switch section **134**-1, and use the modulated waveforms to generate the control signals **136** for each.

(239) After adjusting the relative energy outputs at **4226**, control circuitry can again determine or assess whether the unbalanced condition persists at **4228**. If the condition persists, then the method can revert to step **4226** as described above (as indicated by **4230**). If the unbalanced condition requirement is not met, then method **4200** can proceed to step **4232** where the reduction in supply of energy from IC module **108**-IC can be stopped. This can include a reversion to modulation indexes (for IC module **108**-IC and modules **108**-1 through **108**-4) that were in use prior to entering the unbalanced condition, e.g., a reversion to modulation indexes for the balanced condition. Alternatively, this can include an increase in modulation index for the switch section **134**-1 and an decrease in the modulation indexes for cascaded modules **108**-1 through **108**-N of array **1500**-A, to values not necessarily the same as those in use in the prior balanced operation.

(240) The embodiments described with respect to FIGS. **42**A and **42**B can also be combined to compensate for any of the unbalanced conditions described herein. For example, in a case where array **1500**-A has an overall lower SOC than array **1500**-B, then the energy or power supplied by an IC module for array **1500**-A can be increased and the energy or power output of one or more cascaded modules **108** of that array **1500**-A can be correspondingly decreased. Concurrently, the energy or power supplied by an IC module for array **1500**-B can be decreased and the energy or power output of one or more cascaded modules **108** of that array **1500**-B can be correspondingly increased.

(241) The interconnection of arrays **1500** through one or more IC modules **108**-IC enables the effective and fast exchange of energy between arrays **1500** of multiple phases. For example, current passing into system **100** from one of nodes A, B, or C can be used to charge energy sources within the one more modules **108**-IC, while those energy sources can be used for selective discharge of current to the one or more nodes A, B, and C.

Example Embodiments Related to Layouts and Housings

(242) In many of the embodiments herein, the ConSource module is shown or described as being separate from the LCD. However, in any and all embodiments described herein, the ConSource module can be configured such that the LCD is a component thereof. For example, FIG. **43**A is a block diagram depicting an example embodiment of a converter-source module **108** (which can also be referred to as a ConSource module V**1**, V**2**, or V**3**). In this embodiment, module **108** has a common housing or physical encasement **4302** that holds the LCD **114** for module **108**, as well as the Converter V**1** or V**2 206**, **308**, the Energy Buffer **204** and Energy Source **1 202** (and optionally Energy Source **2 304** if present). Thus, in this embodiment module **108** is provided or manufactured as an integrated or unitary device or sub-system.

(243) FIG. **43**B is a block diagram depicting another example embodiment of a converter-source

module **108**. In this embodiment, module **108** has a housing or physical encasement **4303** that holds the LCD for module **108**, as well as the Converter V**1** or V**2 206**, **308**, and the Energy Buffer **204**. Energy Source **1 202** (and optionally Energy Source **2 304** if present) is provided in a separate housing **4304**. Housings **4303** and **4304** can be physically joined, secured, or connected together prior to installation in system **100**, or can be separate entities electrically connected together. Housings **4303**, **4304** can have ports or other access to accommodate electrical connections between the various devices **114**, **206**, **308**, **202**, etc.

(244) FIG. **43**C is a block diagram depicting another example embodiment of a converter-source module **108**. In this embodiment, module **108** has a first housing or physical encasement **4306** that holds LCD **114** for module **108** and a second housing or physical encasement **4308** that holds Converter V**1** or V**2 206**, **308**, and the Energy Buffer **204**. Energy Source **1 202** (and optionally Energy Source **2 304** if present) is provided in a separate housing **4304**. Housings **4306**, **4308**, and **4304** can be physically joined, secured, or connected together prior to installation in system **100**, or can be separate entities electrically connected together. All of the housings **4306**, **4308**, and **4304** can have ports or other access to accommodate electrical connections between the various devices **114**, **206**, **308**, **202**, etc.

(245) In any and all embodiments described herein, the various circuitry components can be integrated on or more substrates to reduce the form factor. For example, the LCD can be part of a ConSource module as described with respect to FIGS. **43**A-**43**C. FIG. **44**A is a schematic view depicting an example embodiment where the LCD **114**, converter V**1** or V**2 206**, **308**, and Energy Buffer **204** are each mounted or secured to a single common substrate **4402**, which can be a single printed circuit board (PCB). These components can be electrically coupled with substrate **4402** and each other to permit the exchanging of signals or data therebetween. Other passive or active componentry can likewise be mounted or secured to substrate **4402**.

(246) FIG. **44**B is a schematic view depicting an example embodiment where the converter V**1** or V**2 206**, **308** and Energy Buffer **204** are each mounted or secured to a single common substrate **4404**, which can be a single printed circuit board (PCB). These components can be electrically coupled with substrate **4404** and each other to permit the exchanging of signals or data therebetween. The LCD **114** is mounted or secured to a different substrate **4406**, which can also be a single PCB. Other passive or active componentry can likewise be mounted or secured to substrates **4404** and **4406**. Communication between the LCD and the components on substrate **4404** can occur over one or more buses, wires, or fiber optics.

(247) In the embodiments described herein, intra-phase balancing can be achieved by the one or more intra-phase balancing controllers, and inter-phase balancing can be achieved by one or more inter-phase balancing controllers. These intra-phase balancing controllers and inter-phase balancing controllers can be implemented in hardware, software, or a combination thereof. These intra-phase balancing controllers and inter-phase balancing controllers can be implemented wholly by a device, such as the master control device. These intra-phase balancing controllers and inter-phase balancing controllers can be implemented in distributed fashion between multiple devices, such as the master control device and one or more local control devices.

(248) System **100** can operate across a wide range of frequencies as may be required in various stationary and mobile applications. For example, the system AC output frequency in stationary applications will often be 60 Hz. In an embodiment where a MSOFET is used for each switch in circuitry **207** (FIG. **5**A), the switching frequency of each MOSFET (Fsw) can be in a range of 1 Khz-2 kHz, or more. In an example where there are 8 modules in each phase array, then the resulting frequency of pulsations in the AC output voltage will be 2F.sub.SW*N=16 kHz-32 kHz, or more. The switching frequency of conventional systems, like IGBT based high power inverters, is often less 5 kHz. In mobile applications the system frequency will depend on the needs of the motor(s), which commonly range from 0 Hz to 2000 Hz, or more, for a sinusoidal output waveform. In an example embodiment where Fsw of the switches of circuitry **207** is 5 Khz, then

the switching frequency of an example system **100** (equivalent output pulsations) with five modules in series would be 2*5 kHz*5=50 kHz. This is compared to a conventional power inverter that has a switching frequency is less than 20 kHz. These examples merely illustrate the enhanced performance of system **100** over conventional systems, and are in no way intended to be limiting.

(249) In all of the embodiments described herein, the primary energy source of each module of a particular system can have the same voltage (either standard operating voltage or nominal voltage). Such a configuration simplifies management and construction of the system. The primary and second energy sources can also have the same voltage (standard or nominal). Other configurations can be implemented, such as those where primary energy sources of different modules of the same system have different voltages (standard or nominal), and those where the primary and secondary energy sources of a module have different voltages (standard or nominal). Still other configurations can be implemented, where primary energy sources of modules of a system have primary energy source batteries that are different chemistries, or where modules of the system have a primary energy source battery of a first chemistry, and a secondary energy source battery of a second chemistry. The modules that differ from each other can be based on placement in the system (e.g., modules within a phase array are different than the IC module(s)).

(250) In FIGS. **1**A-**8**F, **11**, **13**, **15-30**, **32**, **41**A-**41**F, and **43**A-**44**B, various constituents of the figures (e.g., elements, components, devices, systems, and/or functional blocks) are depicted as being coupled with or connected to one or more other constituents (e.g., elements, components, devices, systems, and/or functional blocks). These constituents are often shown as being coupled or connected without the presence of an intervening entity, such as in a direct coupling or connection. Those of ordinary skill in the art will readily recognize, in light of the present description, that these couplings or connections can be direct (without one or more intervening components) or indirect (with one or more intervening components not shown). Thus, this paragraph serves as antecedent support for all couplings or connections being direct couplings connections or indirect couplings or connections.

(251) A detailed discussion regarding systems (e.g., an ACi-battery pack), devices, and methods that may be used in conjunction with the systems, devices, and methods described herein is provided in International Publication No. WO 2019/183553, filed Mar. 22, 2019, entitled Systems And Methods For Power Management And Control, which is incorporated by reference herein for all purposes as if set forth in full.

(252) The embodiments described herein, when used as a battery pack, e.g., in the automotive industry, permit the elimination of the conventional Battery Management System as a sub-system accompanying each battery module. The functionality typically performed by the Battery Management System is subsumed or replaced by the different and in many ways greater functionality of the system embodiments described herein.

(253) A person of ordinary skill in the art would understand that the a "module" as that term is used herein, refers to a device, assembly, or sub-system within system **100**, and that system **100** does not have to be configured to permit each individual module to be physically removable and replaceable with respect to the other modules. For example, system **100** may be packaged in a common housing that does not permit removal and replacement any one module, without disassembly of the system as a whole. However, any and all embodiments herein can be configured such that each module is removable and replaceable with respect to the other modules in a convenient fashion, such as without disassembly of the system.

(254) The term "master control device" is used herein in a broad sense and does not require implementation of any specific protocol such as a master and slave relationship with any other device, such as the local control device.

(255) The term "output" is used herein in a broad sense, and does not preclude functioning in a bidirectional manner as both an output and an input. Similarly, the term "input" is used herein in a broad sense, and does not preclude functioning in a bidirectional manner as both an input and an

output.

(256) The terms "terminal" and "port" are used herein in a broad sense, can be either unidirectional or bidirectional, can be an input or an output, and do not require a specific physical or mechanical structure, such as a female or male configuration.

(257) The example embodiments described herein can be used with one or more cooling systems to dissipate heat from any and all components of the system (e.g., switch circuitry, energy source, energy buffer, control circuitry, etc.). The cooling systems can utilize a cooling medium such as a gas, liquid, or solid. The cooling systems can utilize one or more piezo cooling elements.

(258) Various aspects of the present subject matter are set forth below, in review of, and/or in supplementation to, the embodiments described thus far, with the emphasis here being on the interrelation and interchangeability of the following embodiments. In other words, an emphasis is on the fact that each feature of the embodiments can be combined with each and every other feature unless explicitly stated otherwise or logically implausible.

(259) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output voltage of the module. In these embodiments, the module-based energy system further includes a local control device communicatively coupled with the converter-source module, where the local control device is configured to generate multiple switching signals for the multiple switches.

(260) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output voltage of the module. In these embodiments, the module-based energy system further includes a local control device communicatively coupled with the converter-source module, where the first energy source provides the operating power for the local control device.

(261) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output voltage of the module. In these embodiments, the module-based energy system further includes a local control device communicatively coupled with the converter-source module, where the local control device is configured to detect a fault in the converter-source module and generate a fault signal. In these embodiments, the fault signal is indicative of an actual fault or a potential fault. In many of these embodiments, the module-based energy system further includes a master control device communicatively coupled to the local control device, where the local control device is configured to output the fault signal to the master control device.

(262) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output voltage of the module. In these embodiments, the module-based energy system further includes a local control device communicatively coupled with the converter-source module, where the local control device, energy buffer, and converter are implemented together on a single printed circuit board.

(263) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output

voltage of the module. In these embodiments, the module-based energy system further includes a local control device communicatively coupled with the converter-source module, where the local control device, energy buffer, and converter are housed within a common housing that does not house the first energy source.

(264) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output voltage of the module. In these embodiments, the module-based energy system further includes a local control device communicatively coupled with the converter-source module, where the local control device, first energy source, energy buffer, and converter are housed within a common housing that does not house another converter-source module.

(265) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output voltage of the module. In these embodiments, the module-based energy system further includes a local control device communicatively coupled with the converter-source module, where the local control device, energy buffer, and converter are housed within a common housing that does not house the first energy source.

(266) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output voltage of the module, and where the energy buffer and converter are implemented together on a single printed circuit board.

(267) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source including a fuel cell, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output voltage of the module.

(268) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the energy buffer includes a Z-source network including two inductors and two capacitors, or a quasi Z-source network including two inductors, two capacitors and a diode. In these embodiments, the converter-source module further includes a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output voltage of the module.

(269) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, a second energy source, and a converter including a first input, a second input, and a third input, where the first and third inputs are coupled with the first energy source and the energy buffer, where the second and third inputs are coupled with the second energy source, where the converter further includes multiple switches configured to select an output voltage of the module, and where both the first and second energy sources each include a battery or both the first and second energy sources each do not include a battery.

(270) In many of these embodiments, the first and second energy sources each include a capacitor or a fuel cell. In many of these embodiments, the converter includes a first switch, an inductor, and a second switch, where the first switch is coupled between the first input and a first node, the

inductor is coupled between the second input and the first node, and the second switch is coupled between the third input and the first node. In many of these embodiments, the multiple switches include a third switch, a fourth switch, a fifth switch, and a sixth switch. In many of these embodiments, both the first and second energy sources each include a battery, where the second energy source further includes a first capacitor in parallel with the battery. In many of these embodiments, both the first and second energy sources each include a battery, where the second energy source further includes a first capacitor in parallel with the battery and a second capacitor in parallel with the battery.

(271) In many embodiments, a module-based energy system includes a converter-source module. In these embodiments, the converter-source module includes a first energy source, an energy buffer coupled with the first energy source, and a converter coupled with the first energy source and the energy buffer, where the converter includes multiple switches configured to select an output voltage of the module. In these embodiments, the converter-source module further includes a first output port for connection to a primary load or another converter-source module and a second output port for connection to an auxiliary load.

(272) In many of these embodiments, the auxiliary load is a first auxiliary load and the converter-source module includes a third output port for connection to a second auxiliary load. In many of these embodiments, the first output port is coupled with a primary load or another converter-source module, the second output port is coupled with the first auxiliary load, and the third output port is coupled with the second auxiliary load. In many of these embodiments, the converter includes a first input, a second input, and a third input, where the first and third inputs are coupled with the first energy source, the energy buffer, and the second output port, and where the second and third inputs are coupled with the third output port. In many of these embodiments, the converter includes a first switch, an inductor, and a second switch, where the first switch is coupled between the first input and a first node, the inductor is coupled between the second input and the first node, and the second switch is coupled between the third input and the first node. In many of these embodiments, the multiple switches include a third switch, a fourth switch, a fifth switch, and a sixth switch. In many of these embodiments, third switch, fourth switch, fifth switch, and sixth switch are coupled together as an H-bridge. In many of these embodiments, the first output port includes a first output and a second output, where the third switch is coupled between the first input and the first output, the fourth switch is coupled between the third input and the first output, the fifth switch is coupled between the first input and the second output, and the sixth switch is coupled between the third input and the second output.

(273) In many of the aforementioned embodiments, the module-based energy system further includes multiple converter-source modules coupled with the converter-source module in an array.

(274) In many of these embodiments, each of the converter-source modules in the multiple converter-source modules includes a first energy source, an energy buffer coupled with the first energy source, and a converter including multiple switches configured to select an output voltage of that converter-source module. In many of these embodiments, the multiple switches select between a first voltage with a positive polarity, a zero or reference voltage, and the first voltage with a negative polarity. In many of these embodiments, the first voltage is a direct current (DC) voltage. In many of these embodiments, the array is configured to output an alternating current (AC) signal.

(275) In many of the aforementioned embodiments, the converter includes one or more sensors configured to output one or more sensed signals indicative of a temperature of the first energy source, a state of charge of the first energy source, a voltage of the first energy source, or a current.

(276) In many of the aforementioned embodiments, the module-based energy system further includes a local control device communicatively coupled with the converter-source module.

(277) In many of these embodiments, the module-based energy system further includes multiple converter-source modules and multiple local control devices, where each local control device in the

multiple local control devices is dedicated for use with one converter-source module of the multiple converter-source modules. In many of these embodiments, the converter-source module is a first converter-source module, where the system includes a second converter-source module, and where the local control device controls both the first and second converter-source modules.

(278) In many of the aforementioned embodiments, the local control device includes processing circuitry and a memory communicatively coupled with the processing circuitry, where the memory includes instructions executable by the processing circuitry.

(279) In many of the aforementioned embodiments, the local control device is configured to generate switching signals for the converter using pulse width modulation.

(280) In many of these embodiments, the local control device is configured to modulate or scale a received reference signal and use the modulated reference signal for generation of the switching signals. In many of these embodiments, the local control device is configured to use a received modulation index to modulate the received reference signal.

(281) In many of the aforementioned embodiments, the local control device is configured to receive one or more signals indicative of one or more of the following operating characteristics of the converter-source module or a component thereof: temperature, state of charge, capacity, state of health, voltage, or current.

(282) In many of these embodiments, the local control device is configured to communicate, to a master control device, information indicative of one or more of the following operating characteristics of the converter-source module or a component thereof: temperature, state of charge, capacity, state of health, voltage, or current.

(283) In many of the aforementioned embodiments, the local control device is powered only by the first energy source.

(284) In many of the aforementioned embodiments, the local control device is powered by an energy source other than the first energy source.

(285) In many of the aforementioned embodiments, the converter-source module includes a second energy source, where the local control device is configured to cause the converter-source module to actively filter a second order harmonic in an output current from the first energy source with current from the second energy source.

(286) In many of these embodiments, the first energy source includes a battery and the second energy source includes a capacitor. In many of these embodiments, the capacitor of the second energy source is an ultra-capacitor or super-capacitor.

(287) In many of the aforementioned embodiments, the converter-source module includes a second energy source, where the local control device is configured to control the converter to manage power transfer: from the first energy source to a cumulative load of converter-source modules, from the second energy source to the cumulative load of converter-source modules, and between the first energy source and second energy source.

(288) In many of these embodiments, power transfer between the first energy source and second energy source includes power transfer from the first energy source to the second energy source and power transfer from the second energy source to the first energy source. In many of these embodiments, the local control device is configured to control the converter to manage power transfer based, at least in part, on a power consumption of a first auxiliary load and a power consumption of a second auxiliary load. In many of these embodiments, the local control device includes a processor and memory, where the memory includes instructions that, when executed by the processing circuitry, cause the processing circuitry to manage power transfer: from the first energy source to a cumulative load of converter-source modules, from the second energy source to the cumulative load of converter-source modules, and between the first energy source and second energy source. In many of these embodiments, the local control device is configured to manage power transfer by generation of switching signals for the converter.

(289) In many of the aforementioned embodiments, the module-based energy system further

includes a master control device configured to manage one or more operating parameters of the converter-source module relative to one or more operating parameters of other converter-source modules within the system.

(290) In many of the aforementioned embodiments, the module-based energy system further includes a master control device communicatively coupled with the local control device.

(291) In many of these embodiments, the master control device is communicatively coupled with the local control device over a serial data cable. In many of these embodiments, the master control device includes processing circuitry and a memory communicatively coupled with the processing circuitry, where the memory includes instructions executable by the processing circuitry. In many of these embodiments, the module-based energy system further includes multiple local control devices coupled with multiple converter-source modules, where the master control device is communicatively coupled with each of the local control devices of the multiple local control devices. In many of these embodiments, the master control device is configured to read data indicative of one or more operating characteristics of the multiple converter-source modules, and to determine a contribution for at least one converter-source module of the multiple converter-source modules. In many of these embodiments, the master control device is configured to determine a contribution for each of the multiple converter-source modules. In many of these embodiments, the master control device is configured to output a modulation or scaling index for each of the multiple converter-source modules, where the modulation or scaling index is indicative of power flow contribution. In many of these embodiments, the master control device is configured to output a reference signal to each of the local control devices, where each of the local control devices is configured to modulate or scale the reference signal with a received modulation or scaling index, and generate switching signals based on the modulated or scaled reference signal.

(292) In many of the aforementioned embodiments, the module-based energy system is configured for operation in a mobile entity.

(293) In many of these embodiments, the mobile entity is one of: a car, a bus, a truck, a motorcycle, a scooter, an industrial vehicle, a mining vehicle, a flying vehicle, a maritime vessel, a locomotive, a train or rail-based vehicle, or a military vehicle.

(294) In many of the aforementioned embodiments, the module-based energy system is configured for operation as a stationary energy system.

(295) In many of these embodiments, the stationary energy system is one of: a residential storage system, an industrial storage system, a commercial storage system, a data center storage system, a grid, a micro-grid, or a charging station.

(296) In many of the aforementioned embodiments, the module-based energy system is configured as a battery pack for an electric vehicle.

(297) In many embodiments, a module-based energy system includes multiple converter-source modules, each including a first energy source, an energy buffer, and a converter electrically coupled together, where the multiple converter-source modules are electrically coupled together in an array. In these embodiments, the module-based energy system further includes control circuitry communicatively coupled with the multiple converter-source modules, where the control circuitry is configured to monitor at least one operating characteristic of each of the multiple converter-source modules and, based on the monitored at least one operating characteristic, independently control each converter-source module within the multiple converter-source modules for performance optimization of the array.

(298) In many of these embodiments, the at least one operating characteristic is selected from: state of charge, temperature, state of health, capacity, fault presence, voltage, or current. In many of these embodiments temperature is at least one of: a temperature of the first energy source or a component thereof, a temperature of the energy buffer or a component thereof, a temperature of the converter or a component thereof. In many of these embodiments, capacity is at least one of: capacity of the first energy source or capacity of one or more components of the first energy

source. In many of these embodiments, fault presence is at least one of: an indication of the presence of a measured fault, an indication of the presence of a potential fault; an indication of the presence of an alarm condition, or an indication of the presence of a warning condition. In many of these embodiments, voltage is at least one of: a voltage of the first energy source or a component thereof, a voltage of the energy buffer or a component thereof, a voltage of the converter or a component thereof. In many of these embodiments, current is at least once of: a current of the first energy source or a component thereof, a current of the energy buffer or a component thereof, a current of the converter or a component thereof. In many of these embodiments, each converter-source module includes at least one sensor to sense the at least one operating characteristic. In many of these embodiments, the control circuitry is configured to monitor all of the following operating characteristics: state of charge, temperature, state of health, capacity, fault presence, voltage, and current. In many of these embodiments, the control circuitry is configured to independently control discharging or charging of each converter-source module by generation of multiple switching signals and output of the multiple switching signals to the converter of each converter-source module. In many of these embodiments, the control circuitry is configured to generate the multiple switching signals with pulse width modulation or hysteresis.

(299) In many of these embodiments, at least one converter-source module of the multiple converter-source modules is a converter-source module as described in many of the aforementioned embodiments.

(300) In many of these embodiments, every converter-source module of the multiple converter-source modules is a converter-source module as described in many of the aforementioned embodiments.

(301) In many of these embodiments, the control circuitry is configured to independently control discharging or charging of each converter-source module within the multiple converter-source modules for performance optimization of the array. In many of these embodiments, the control circuitry is configured to independently control discharging or charging of each converter-source module based on a power requirement of a load coupled with the array. In many of these embodiments, the load is a motor, a commercial structure, a residential structure, an industrial structure, or an energy grid. In many of these embodiments, the control circuitry includes multiple local control devices and a master control device communicatively coupled with the multiple local control devices.

(302) In many embodiments, a module-based energy system includes an array of N converter-source modules, where N is 2 or greater, where each of the N converter-source modules is connected in series, where each of the N converter-source modules is configured according to any of the aforementioned embodiments, and where the array includes a first output terminal of a first converter-source module and a second output terminal of an Nth converter-source module.

(303) In many of these embodiments, the module-based energy system further includes multiple local control devices, each communicatively coupled with one or more of the N converter-source modules. In many of these embodiments, the module-based energy system further includes a master controller communicatively coupled with the multiple local control devices. In many of these embodiments, the module-based energy system further includes a load connected between the first and second output terminals. In many of these systems, the load is one of a DC load or a single-phase AC load.

(304) In many embodiments, a module-based energy system includes M arrays of converter-source modules, where M is 2 or greater, where each of the M arrays includes N converter-source modules, where N is 2 or greater, where each of the N converter-source modules is connected in series in each of the M arrays, where each of the N converter-source modules is configured according to any of aforementioned embodiments, where each of the M arrays includes an individual output terminal of a first converter-source module, and where an Nth converter-source module of each of the M arrays is connected to a common output terminal.

(305) In many of these embodiments, the module-based energy system further includes multiple local control devices, each communicatively coupled with one or more of the N converter-source modules of each of the M arrays. In many of these embodiments, the module-based energy system further includes a master controller communicatively coupled with the multiple local control devices. In many of these embodiments, the M arrays includes first and second arrays. In many of these embodiments, the module-based energy system further includes a load connected between the individual output terminals of the first and second arrays. In many of these embodiments, the common output terminal is coupled to a neutral of the load. In many of these embodiments, the module-based energy system further includes a load connected between the common output terminal and a joint coupling of the individual output terminals of the first and second arrays. In many of these embodiments, the load is one of a DC load or a single-phase AC load. In many of these embodiments, the M arrays includes first, second and third arrays. In many of these embodiments, the module-based energy system further includes a three-phase load connected between the individual output terminals of the first, second and third arrays. In many of these embodiments, the common output terminal is coupled to a neutral of the load. In many of these embodiments, the module-based energy system further includes a DC or single phase AC load connected between the common output terminal and a joint coupling of the individual output terminals of the first, second and third arrays.

(306) In many of these embodiments, the module-based energy system further includes multiple local control devices, each communicatively coupled with one or more of the N converter-source modules of the first, second, third, fourth, fifth, sixth, seventh, eighth, ninth, tenth, eleventh and twelfth arrays. In many of these embodiments, the module-based energy system further includes a master controller communicatively coupled with the multiple local control devices.

(307) In many embodiments, a module-based energy system includes multiple connected converter-source modules and control circuitry, where the control circuitry is configured to adjust a contribution of one or more of the converter-source modules based on status information associated with one or more of the converter-source modules.

(308) In many of these embodiments, the converter-source module includes a converter-source module according to many of the aforementioned embodiments.

(309) In many of these embodiments, the converter-source module includes an energy source including at least one energy storage element, an energy buffer, and a converter. In many of these embodiments, the status information includes one or more of state of charge, state of health, temperature, capacity, current, or voltage of the converter-source module or a component thereof. In many of these embodiments, the master control device is configured to balance state of charge (SOC) of the multiple connected converter-source modules. In many of these embodiments, the control circuitry includes processing circuitry and at least one memory having instructions stored thereon that, when executed by the processing circuitry, cause the processing circuitry to cause adjustment of the contribution of one or more converter-source modules based on status information associated with one or more of the converter-source modules. In many of these embodiments, the processing circuitry and at least one memory are components of a master control device, a local control device, or distributed between a master control device and one or more local control devices.

(310) In many of these embodiments, the control circuitry is configured to cause the contribution of a first converter-source module to be lowered with respect to one or more other converter-source modules based on status information of the first converter-source module and the one or more other converter-source modules. In many of these embodiments, the status information of the first converter-source module indicates at least one of the following as compared to status information of the one or more other converter-source modules: a relatively lower state of charge, a relatively lower state of health, a relatively lower capacity, a relatively lower voltage, a relatively lower current, a relatively higher temperature, or a fault.

(311) In many of these embodiments, the control circuitry is configured to cause the contribution of a first converter-source module to be raised with respect to one or more other converter-source modules based on status information of the first converter-source module and the one or more other converter-source modules. In many of these embodiments, the status information of the first converter-source module indicates at least one of the following as compared to status information of the one or more other converter-source modules: a relatively higher state of charge, a relatively higher state of health, a relatively higher capacity, a relatively higher voltage, a relatively higher current, a relatively lower temperature, or absence of a fault.

(312) In many of these embodiments, the contribution is an output power over time of the first converter-source module. In many of these embodiments, the control circuitry includes a master control device and multiple local control devices. In many of these embodiments, the master control device is configured to generate a multiple modulation indexes for the multiple converter-source modules, with one modulation index independently generated for each converter-source module of the multiple converter-source modules.

(313) In many of these embodiments, the master control device includes an intra-phase balancing controller. In many of these embodiments, the intra-phase balancing controller is configured to generate a modulation index for each converter-source module. In many of these embodiments, a modulation index for a converter-source module is determined based on one or more of a peak voltage Vpk of a reference voltage Vr of the module-based energy system, state of charge of the converter-source module, temperature of the converter-source module, capacity of the converter-source module, current of the converter-source module, or voltage of the converter-source module. In many of these embodiments, the master control device further includes a peak detector for detecting a peak voltage Vpk of a reference voltage Vr of the module-based energy system. In many of these embodiments, the master control device is configured to generate a normalized reference waveform Vrn from a reference voltage Vr. In many of these embodiments, the master control device is configured to generate the normalized reference waveform Vrn from the reference voltage Vr by division of the reference voltage Vr by its peak voltage Vpk. In many of these embodiments, the master control device is configured to output a normalized reference waveform Vrn to each of the multiple local control devices. In many of these embodiments, each local control device of the multiple local control devices is configured to modulate the received normalized reference waveform Vrn by the received modulation index. In many of these embodiments, each local control device of the multiple local control devices is configured to generate switching signals for a converter-source module based on the modulated reference waveform. In many of these embodiments, each local control device of the multiple local control devices is configured to generate switching signals for a converter-source module based on a pulse width modulation technique implemented with the modulated reference waveform.

(314) In many of these embodiments, the multiple modulation indexes is generated to ensure a sum of generated voltages from the multiple converter-source modules does not exceed a peak voltage Vpk. In many of these embodiments, the multiple modulation indexes Mi are generated to cause states of charge (SOC) of energy sources of the multiple converter-source modules to converge towards a balanced condition. In many of these embodiments, the multiple modulation indexes Mi are generated to cause states of health (SOH) of the multiple converter-source modules to converge towards a balanced condition. In many of these embodiments, the multiple modulation indexes Mi are generated to cause capacities of the multiple converter-source modules to converge towards a balanced condition. In many of these embodiments, the multiple modulation indexes Mi are generated to cause voltages of the multiple converter-source modules to converge towards a balanced condition. In many of these embodiments, the multiple modulation indexes Mi are generated to cause currents of the multiple converter-source modules to converge towards a balanced condition. In many of these embodiments, the multiple modulation indexes Mi are generated to cause temperatures of the multiple converter-source modules to converge towards a

balanced condition. In many of these embodiments, the multiple modulation indexes Mi are generated to reduce the contribution of one or more converter-source modules having a fault condition as compared to one or more other converter source modules not having a fault condition.

(315) In many of these embodiments, the control circuitry includes one or both of an inter-phase balancing controller or an intra-phase balancing controller. In many of these embodiments, the multiple converter-source modules is arranged in a multi-dimensional array. In many of these embodiments, the intra-phase balancing controller is configured to adjust a contribution of the multiple converter-source modules within a one-dimensional array of the multi-dimensional array. In many of these embodiments, the inter-phase balancing controller is configured to control one or more of neutral point shifting or contribution of converter-source modules that are common to each phase.

(316) In many of the aforementioned embodiments, the module-based energy system is one of single phase or multi-phase. In many of these embodiments, the module-based energy system is a multi-phase module-based energy system outputting signals in three-phases, four-phases, five-phases, or six-phases.

(317) In many of the aforementioned embodiments, the multiple converter-source modules are arranged in a multi-dimensional array.

(318) In many of the aforementioned embodiments, the multiple converter-source modules are arranged in accordance with any of many of the aforementioned embodiments.

(319) In many of the aforementioned embodiments, the module-based energy system is configured for operation in an electric or hybrid mobile vehicle. In many of these embodiments, the electric or hybrid mobile vehicle is one of: a car, a bus, a truck, a motorcycle, a scooter, an industrial vehicle, a mining vehicle, a flying vehicle, a maritime vessel, a locomotive or rail-based vehicle, or a military vehicle.

(320) In many of the aforementioned embodiments, the module-based energy system is configured for operation as a stationary energy system. In many of these embodiments, the stationary energy system is one of: a residential system, an industrial system, a commercial system, a data center storage system, a grid, a micro-grid, or a charging station.

(321) In many of the aforementioned embodiments, the module-based energy system is configured as a battery pack for an electric vehicle.

(322) In many embodiments, a module-based energy system includes multiple connected converter-source modules and control circuitry, where the control circuitry is configured to adjust power supply to one or more of the converter-source modules based on status information associated with one or more of the converter-source modules. In many of these embodiments, each converter-source module includes a converter-source module according to many of the aforementioned embodiments.

(323) In many of these embodiments, each converter-source module includes an energy source including at least one energy storage element, an energy buffer, and a converter. In many of these embodiments, the control circuitry is configured to independently determine the amount of charge each converter-source module with the system receives from a power supply external to the system. In many of these embodiments, the control circuitry is configured to independently determine the amount of charge each converter-source module with the system receives from a power supply external to the system based on status information associated with one or more of the converter-source modules or components thereof, where the status information includes one or more of: state of charge (SOC), state of health (SOH), capacity, temperature, voltage, current, presence of a fault, or absence of a fault. In many of these embodiments, the multiple converter-source modules are arranged in a multi-dimensional array. In many of these embodiments, the multiple converter-source modules is arranged in accordance with many of the aforementioned embodiments.

(324) In many embodiments, a converter-source module includes an energy source including at least one energy storage element, an energy buffer, and a converter including multiple, the

converter configured to generate an output voltage based on a combination of the multiple switches.

(325) In many of these embodiments, an output of the energy source is couplable to an input terminal of the energy buffer. In many of these embodiments, an output of the energy buffer is couplable to an input terminal of the converter. In many of these embodiments, the energy storage element is one of an ultra-capacitor, a battery including at least one cell or multiple battery cells connected in series and/or in parallel, or a fuel-cell. In many of these embodiments, the energy buffer includes one or more of: electrolytic capacitors, film capacitors, a Z-source network including two inductors and two capacitors, or a Quasi Z-source network including two inductors, two capacitors and a diode. In many of these embodiments, each of the multiple switches includes at least one of a semiconductor MOSFET or a semiconductor IGBT. In many of these embodiments, the converter is configured to generate three different voltage outputs by different combinations of the multiple switches. In many of these embodiments, the energy source is configured to output a direct current voltage VDC, and the three different voltage outputs are +VDC, 0, and −VDC. In many of these embodiments, the converter-source module is configured to receive switching signals for the multiple switches from a local control device.

(326) In many embodiments, an energy system includes at least two converter-source modules according to many of the aforementioned embodiments.

(327) In many of these embodiments, the at least two converter-source modules are connected in one of a one-dimensional array or a multi-dimensional array. In many of these embodiments, a least two one-dimensional arrays are connected together at different rows and columns directly or via additional converter-source modules. In many of these embodiments, the energy system includes at least two local control devices, one local control device for each converter-source module. In many of these embodiments, each local control device manages energy from the energy source, protects the energy buffer, and controls the converter.

(328) In many embodiments, a module-based energy system includes a local control device and a converter-source module connected to the local control device, where the converter-source module includes an energy source having a storage element, first and second outputs of the energy source being connected to first and second inputs of an energy buffer, first and second outputs of the energy buffer being connected to first and second inputs of a converter, the converter including at least four switches to generate three voltage levels including a first voltage level with a positive polarity, a zero or reference voltage level, and the first voltage level with a negative polarity, where the three voltage levels are generated by connection of the first voltage level between the first and second inputs of the converter to first and second outputs of the converter by different combinations of the at least four switches.

(329) In many of these embodiments, the storage element includes one of an ultra-capacitor, a battery module including one or more connected battery cells, and a fuel-cell module. In many of these embodiments, the energy buffer includes one of an electrolytic and/or film capacitor, a Z-source network formed by two inductors and two electrolytic and/or film capacitors, and a Quasi Z-source network formed by two inductors, two electrolytic and/or film capacitors and a diode. In many of these embodiments, the switches are configured as semiconductor switches. In many of these embodiments, the energy source includes a primary energy source and a secondary energy source, where in the primary energy source includes a storage element including one of an ultra-capacitor, a battery module including one or more connected battery cells, and a fuel-cell module. In many of these embodiments, the first and second outputs of the primary energy source are coupled to first and second input terminals of an energy buffer, where the energy buffer includes one of an electrolytic and/or film capacitor, a Z-source network formed by two inductors and two electrolytic and/or film capacitors, and a Quasi Z-source network formed by two inductors, two electrolytic and/or film capacitors and a diode. In many of these embodiments, a second output of the energy buffer is connected to a second output of the secondary energy source, and where a first

output of the secondary energy source is connected to the second input of the converter. In many of these embodiments, the secondary energy source includes a storage element including one of an electrolytic and/or film capacitor, an ultra-capacitor, a battery module including one or more connected battery cells, an electrolytic and/or film capacitor connected in parallel with an ultra-capacitor, an electrolytic and/or film capacitor connected in parallel with a battery module including one or more connected battery cells, an electrolytic and/or film capacitor connected in parallel with ultra-capacitor and battery module including one or more connected battery cells. In many of these embodiments, the converter includes six switches. In many of these embodiments, the converter-source module is configured to power first and second auxiliary loads.

(330) In many of these embodiments, the system further includes a balancing controller. In many of these embodiments, the balancing controller is a single phase balancing controller. In many of these embodiments, the balancing controller includes a peak detector, a divider and an intra-phase balancing controller. In many of these embodiments, the system further includes multiple converter-source modules, and the balancing controller is configured to balance state of charge and temperature among the multiple converter-source modules of the system. In many of these embodiments, the balancing controller is a three phase balancing controller. In many of these embodiments, the balancing controller includes an interphase balancing controller and a multiple intra-phase controllers. In many of these embodiments, the system further includes multiple converter-source modules, and the balancing controller is configured to balance state of charge and temperature among the multiple converter-source modules of the system.

(331) In many embodiments, a module-based energy system is provided, including a converter-source module, including: a first energy source; and a converter coupled with the first energy source, where the converter includes multiple switches configured to select an output voltage of the module.

(332) In many embodiments, a method of supplying an output power from a module-based energy system is provided, the method including: receiving, by control circuitry of the system, status information from at least one of multiple converter-source modules of the system, where each converter-source module includes an energy source and a converter and where each converter-source module is configured to contribute power to an output power of the system; and controlling, by the control circuitry, a power contribution of at least one converter-source module of the multiple converter-source modules based on the status information.

(333) In these embodiments, the control circuitry can include a master control device and multiple local control devices. The master control device can receive the status information from at least one local control device, and the method can further include outputting a reference waveform and a modulation index from the master control device to the at least one local control device. The method can further include: modulating, by the local control device, the reference waveform with the modulation index; and generating multiple switching signals for a converter of a converter-source module associated with the local control device based, at least in part, on the modulated reference waveform. The switching signals can be generated with pulse width modulation.

(334) In these embodiments, controlling, by the control circuitry, the power contribution of the at least one converter-source module can include: generating and outputting multiple switching signals from the control circuitry to the converter of the at least one converter-source module, where the method further includes switching, by the converter, an output voltage of the at least one converter-source module.

(335) In these embodiments, controlling, by the control circuitry, the power contribution of the at least one converter-source module can include: reducing the power contribution of the at least one converter-source module or raising the power contribution of the at least one converter-source module. The power contribution can be reduced or raised as compared to a preceding power contribution of the at least one converter-source module or as compared to the power contribution of one or more other converter-source modules.

(336) In these embodiments, the control circuitry can control the power contribution of every converter-source module of the multiple converter-source modules.

(337) In these embodiments, the control circuitry can control the power contribution according to a pulse width modulation or hysteresis technique.

(338) In these embodiments, the control circuitry can repeatedly receive status information for every converter-source module, where the status information is specific to each individual converter-source module. The control circuitry can control every converter-source module based on the status information, where the control occurs in real time.

(339) In many embodiments, a method of charging a module-based energy system is provided that includes: receiving, by control circuitry of the system, status information from at least one of multiple converter-source modules of the system, where each converter-source module includes an energy source and a converter and where each converter-source module is configured to be charged by a power supply; and controlling, by the control circuitry, a power consumption of at least one converter-source module of the multiple converter-source modules based on the status information.

(340) In these embodiments, controlling, by the control circuitry, the power consumption of the at least one converter-source module can include: generating and outputting multiple switching signals from the control circuitry to the converter of the at least one converter-source module, and where the method can further include switching, by the converter, multiple switches such that the power consumption of at least one converter-source module is reduced or raised, optionally where the power consumption is reduced or raised as compared to a preceding power consumption of the at least one converter-source module or as compared to the power consumption of one or more other converter-source modules.

(341) In many embodiments, a module-based energy system is provided, the system including: a first array of cascaded modules configured to output a first voltage waveform to a load; a second array of cascaded modules configured to output a second voltage waveform to the load, where the first and second voltage waveforms each have a different phase angle; and an interconnection module coupled to both the first array and the second array, where the interconnection module includes an energy source and switch circuitry, and where the interconnection module is configured to adjust the amount of energy supplied by the energy source to the first and/or second arrays.

(342) In many embodiments, the first array and second array are positioned electrically between the load and the interconnection module.

(343) In some embodiments, the system further includes control circuitry configured to control the switch circuitry, where the energy source has a positive node and a negative node, and where the switch circuitry of the interconnection module is controllable to selectively couple the first and/or second arrays to the first and/or second nodes of the energy source. The control circuitry can be configured to control the switch circuitry such that the energy source discharges relatively more energy to the first array than to the second array under an unbalanced condition between the first and second arrays. The unbalanced condition can relate to state of charge, temperature, capacity, state of health, voltage, and/or current. The control circuitry can be configured to control the switch circuitry such that the energy source discharges relatively more energy to the first array for supply to the load from the first array.

(344) In some embodiments, the unbalanced condition is that the first array has a relatively lower overall energy level than the second array.

(345) In some embodiments, the control circuitry is configured to receive state of charge information from each cascaded module of the first and second arrays, determine if the first array or the second array has a relatively lower overall state of charge, and cause the energy source of the interconnection module to discharge more energy to the one of the first and second arrays having the relatively lower state of charge.

(346) In some embodiments, the unbalanced condition is that the first array has a relatively higher temperature than the second array.

(347) In some embodiments, the control circuitry is configured to receive temperature information from each cascaded module of the first and second arrays, determine if the first array or the second array has a relatively higher temperature, and cause the energy source of the interconnection module to discharge more energy to the one of the first and second arrays having the relatively higher temperature.

(348) In some embodiments, the control circuitry is configured to control a balance of inter-phase energy between the first and second arrays with the energy source of the interconnection module.

(349) In some embodiments, the control circuitry is configured to control the balance of inter-phase energy between the first and second arrays with a shift to a neutral point of the first and second arrays.

(350) In some embodiments, the control circuitry is configured to control the switch circuitry according to a pulse width modulation or hysteresis technique.

(351) In some embodiments, the system is configured to generate the first and second voltage waveforms according to a pulse width modulation technique. The control circuitry can be configured to control the switch circuitry, under a balanced inter-phase condition, such that the interconnection module supplies energy for both the first and second arrays. The energy supplied to the first array can be the same as that to the second array. The control circuitry can be configured to modulate the frequency of operation of the switch circuitry to adjust the energy supplied by the energy source to the first array relative to that to the second array. The control circuitry can be configured to cause relatively more energy to be output by the interconnection module to the first array under an unbalanced inter-phase condition as compared to a balanced inter-phase condition. The control circuitry can be configured to cause relatively less energy to be output by one or more modules of the first array under the unbalanced inter-phase condition as compared to a balanced inter-phase condition. The control circuitry can be configured to maintain the same energy output by one or more modules of the second array and by the interconnection module to the second array under the unbalanced inter-phase condition as compared to a balanced inter-phase condition. The control circuitry can be configured to cause relatively less energy to be output by the interconnection module to the second array and to cause relatively more energy to be output by one or more modules of the second array under an unbalanced inter-phase condition as compared to a balanced inter-phase condition.

(352) The control circuitry can be configured to cause relatively less energy to be output by the interconnection module to the first array under an unbalanced inter-phase condition as compared to a balanced inter-phase condition. The control circuitry can be configured to cause relatively more energy to be output by one or more modules of the first array under the unbalanced inter-phase condition as compared to a balanced inter-phase condition.

(353) In many of the aforementioned embodiments, the control circuitry can include a master control device and a local control device communicatively coupled with the master control device. The master control device can be configured to determine whether the first array and second array are in an unbalanced condition. The master control device can be configured to cause the local control device to generate one or more control signals for the switch circuitry that cause adjustment of energy supplied by the energy source to one of the first and second arrays. The master control device can be configured to modulate a normalized reference signal and output the modulated signal to the local control device. The master control device can be configured to output a reference signal and a modulation index to the local control device, and the local control device can be configured to adjust the reference signal based on the modulation index. The control circuitry can be configured to perform inter-phase balancing by adjusting one or more modulation indexes.

(354) In some embodiments the load is a primary load and the interconnection module is configured to electrically couple to an auxiliary load. The interconnection module can include switch circuitry coupled with an inductor to regulate a voltage supply to the auxiliary load.

(355) In some embodiments, the load is a primary load and the interconnection module is

configured to electrically couple to an auxiliary load, and the control circuitry can be configured to measure a voltage and/or a current for the auxiliary load and control switch circuitry of the interconnection module to regulate a voltage or current supply to the auxiliary load.

(356) In some embodiments, each module of the first array includes an energy source and switch circuitry, and each module of the second array includes an energy source and switch circuitry.

(357) In some embodiments, each module in the system includes a local control device and a common housing, and the switch circuitry, energy source, and local control device for that module are housed within the common housing.

(358) In some embodiments, each module in the system includes a local control device, a first housing, and a second housing, and the local control device and switch circuitry for that module are located in the first housing and the energy source for that module is located in the second housing, and the first and second housings are physically joined to each other.

(359) In some embodiments, each module in the system includes a local control device, a first housing, a second housing, and a third housing, where the local control device for that module is located in the first housing, the switch circuitry for that module is located in the second housing, and the energy source for that module is located in the third housing, and the first, second, and third housings are physically joined together.

(360) In some embodiments, for each module of the system, the switch circuitry and local control device are located on a first printed circuit board.

(361) In some embodiments, the control circuitry is configured to: determine an amount of inter-phase imbalance between the first and second arrays; cause the interconnection module to adjust net energy output to decrease the amount of inter-phase imbalance if below a threshold; and cause a shift to a neutral point of the system to adjust net energy output to decrease the amount of interphase imbalance if above the threshold. The control circuitry can be configured to also cause the interconnection module to adjust net energy output to assist in decrease of the amount of inter-phase imbalance if the amount of interphase imbalance is above the threshold.

(362) In many embodiments, a method of inter-phase balancing in a system is provided, where the system includes a first array of cascaded modules configured to output a first voltage waveform to a load, a second array of cascaded modules configured to output a second voltage waveform to the load, where the first and second voltage waveforms each have a different phase angle, an interconnection module coupled to both the first array and the second array, and control circuitry, and the method includes: determining, by the control circuitry, that an unbalanced condition exists between the first array and second array; and adjusting energy supplied from an energy source of the interconnection module to the first array.

(363) In some embodiments, adjusting energy supplied from the energy source includes increasing net energy supplied from the energy source. The method can further include reducing net energy output by at least one module of the first array. The increase in net energy can be equivalent to the reduction in net energy. The method can further include reducing net energy supplied by all modules of the first array. The method can further include maintaining relative amounts of net energy output from the interconnection module to the second array and from the modules of the second array at a constant level.

(364) In some embodiments, the method further includes: reducing net energy output from the interconnection module to the second array; and increasing net energy output by at least one module of the second array.

(365) In some embodiments, the method further includes increasing a modulation index for switch circuitry of the interconnection module coupled to the first array in order to increase net energy supplied from the energy source of the interconnection module to the first array. The method can further include decreasing a modulation index for the at least one module of the first array to reduce net energy output by at least one module of the first array.

(366) In some embodiments, the unbalanced condition is that the first array has a relatively lower

overall energy level than the second array.

(367) In some embodiments, the method further includes receiving, by the control circuitry, state of charge information from each module of the first and second arrays; and determining, by the control circuitry, if the first array has a relatively lower overall state of charge prior to increasing net energy supplied from an energy source of the interconnection module to the first array.

(368) In some embodiments, the unbalanced condition is that the first array has a relatively higher temperature than the second array.

(369) In some embodiments, the method further includes receiving temperature information from each module of the first and second arrays; and determining if the first array has a relatively higher temperature than the second array prior to increasing net energy supplied from an energy source of the interconnection module to the first array.

(370) In some embodiments, the control circuitry is configured to use the interconnection module to control a balance of inter-phase energy between the first and second arrays.

(371) In some embodiments, the control circuitry includes a master control device and a local control device communicatively coupled with the master control device. The method can further include determining, by the master control device, whether the first array and second array are in an unbalanced condition. The method can further include causing the local control device to generate one or more control signals for the switch circuitry that cause adjustment of energy supplied by the interconnection module to one of the first and second arrays. The method can further include modulating a normalized reference signal and outputting the modulated signal to the local control device. The method can further include outputting a reference signal and a modulation index to the local control device; and adjusting the reference signal based on the modulation index.

(372) In some embodiments, the load is a primary load, and the method further includes providing voltage from the interconnection module to an auxiliary load. The method can further include regulating the voltage supplied by the interconnection module to the auxiliary load. The method can further include measuring a voltage and/or a current for the auxiliary load; and controlling switch circuitry of the interconnection module to regulate the voltage supplied to the auxiliary load.

(373) In some embodiments, adjusting energy supplied from the energy source of the interconnection module to the first array includes reducing net energy supplied from the energy source. The interconnection module can supply energy for both the first and second arrays during a balanced condition. The method can further include increasing net energy output by at least one module of the first array. The increase in net energy is equivalent to the reduction in net energy. The method can further include increasing net energy supplied by all modules of the first array. The method can further include maintaining relative amounts of net energy output from the interconnection module to the second array and from the modules of the second array at a constant level. The method can further include increasing net energy output from the interconnection module to the second array; and reducing net energy output by at least one module of the second array. The method can further include decreasing a modulation index for switch circuitry of the interconnection module coupled to the first array in order to reduce net energy supplied from the energy source of the interconnection module to the first array.

(374) In some embodiments, the method further includes determining or estimating, by the control circuitry, energy output adjustments that cause the first and second array to converge to a balanced condition.

(375) In some embodiments, the unbalanced condition relates to state of charge, temperature, capacity, state of health, voltage, and/or current.

(376) In some embodiments, the method further includes using the interconnection module and neutral point shifting to control a balance of inter-phase energy between the first and second arrays.

(377) In some embodiments, the first and second voltage waveforms are generated according to a pulse width modulation or hysteresis technique.

(378) In some embodiments, the interconnection module supplies energy for both the first and

second arrays during a balanced condition.

(379) In some embodiments, the method further includes performing inter-phase balancing by adjusting one or more modulation indexes.

(380) In some embodiments, determining, by the control circuitry, that an unbalanced condition exists between the first array and second array includes referencing one or more types of qualitative or quantitative information.

(381) In some embodiments, determining, by the control circuitry, that an unbalanced condition exists between the first array and second array includes referencing an SOC parameter of or characterizing one array being less than, more than, or substantially different than the SOC parameter for at least one different array or the system as a whole.

(382) In some embodiments, determining, by the control circuitry, that an unbalanced condition exists between the first array and second array includes referencing a temperature parameter of or characterizing one array being less than, more than, or substantially different than the temperature parameter for at least one different array or the system as a whole.

(383) In some embodiments, determining, by the control circuitry, that an unbalanced condition exists between the first array and second array includes referencing a State of Health (SOH) parameter of or characterizing one array being less than, more than, or substantially different than the SOH parameter for at least one different array or the system as a whole.

(384) In some embodiments, determining, by the control circuitry, that an unbalanced condition exists between the first array and second array includes referencing a voltage parameter of or characterizing one array being less than, more than, or substantially different than the voltage parameter for at least one different array or the system as a whole.

(385) In some embodiments, determining, by the control circuitry, that an unbalanced condition exists between the first array and second array includes referencing a current parameter of or characterizing one array being less than, more than, or substantially different than the current parameter for at least one different array or the system as a whole.

(386) In some embodiments, determining, by the control circuitry, that an unbalanced condition exists between the first array and second array includes referencing a fault or degradation condition.

(387) In some embodiments, the determination that an unbalanced condition exists between the first array and second array is based on a relative difference between the first and second arrays or an absolute factor.

(388) In some embodiments, the method further includes: determining an amount of inter-phase imbalance between the first and second arrays; adjusting net energy output of the interconnection module to decrease the amount of inter-phase imbalance if below a threshold; and shifting a neutral point of the system to adjust net energy output to decrease the amount of interphase imbalance if above the threshold. In some embodiments, the method further includes adjusting net energy output of the interconnection module to assist in decreasing the amount of interphase imbalance if above the threshold.

(389) In many embodiments a control system is provided that is configured to provide control for an module-based energy storage system including a first array of cascaded modules configured to output a first voltage waveform to a load, a second array of cascaded modules configured to output a second voltage waveform to the load, where the first and second voltage waveforms each have a different phase angle, and an interconnection module coupled to both the first array and the second array, where the control system includes: control circuitry and non-transitory memory communicatively coupled to the control circuitry, where a plurality of instructions are stored on the memory that, when executed by the control circuitry, cause the control circuitry to: determine that an unbalanced condition exists between the first array and second array; and cause adjustment of energy supplied from an energy source of the interconnection module to the first array.

(390) In some embodiments, the plurality of instructions further cause the control circuitry to cause

an increase in net energy supplied from the energy source of the interconnection module to the first array. The plurality of instructions can further cause the control circuitry to cause a reduction in net energy output by at least one module of the first array. The increase in net energy can be equivalent to the reduction in net energy. The plurality of instructions can further cause the control circuitry to cause a reduction of net energy supplied by all modules of the first array. The plurality of instructions can further cause the control circuitry to cause relative amounts of net energy output from the interconnection module to the second array and from the modules of the second array to be at a constant level. The plurality of instructions can further cause the control circuitry to cause a reduction in net energy output from the interconnection module to the second array and an increase in net energy output by at least one module of the second array.

(391) In some embodiments, the plurality of instructions can further cause the control circuitry to increase a modulation index for switch circuitry of the interconnection module coupled to the first array in order to increase net energy supplied from the energy source of the interconnection module to the first array. The plurality of instructions can further cause the control circuitry to decrease a modulation index for the at least one module of the first array to reduce net energy output by at least one module of the first array.

(392) In some embodiments, the unbalanced condition is that the first array has a relatively lower overall energy level than the second array.

(393) In some embodiments, the plurality of instructions further cause the control circuitry to determine if the first array has a relatively lower overall state of charge prior to causing an increase in net energy supplied from an energy source of the interconnection module to the first array.

(394) In some embodiments, the unbalanced condition is that the first array has a relatively higher temperature than the second array.

(395) In some embodiments, the plurality of instructions further cause the control circuitry to determine if the first array has a relatively higher temperature than the second array prior to causing an increase in net energy supplied from an energy source of the interconnection module to the first array.

(396) In some embodiments, the plurality of instructions further cause the control circuitry to cause a balance of inter-phase energy between the first and second arrays.

(397) In some embodiments, the control circuitry includes a master control device and a local control device communicatively coupled with the master control device. The plurality of instructions can further cause the control circuitry to generate one or more control signals for the switch circuitry that cause adjustment of energy supplied by the interconnection module to one of the first and second arrays.

(398) In some embodiments, the plurality of instructions can further cause the control circuitry to modulate a normalized reference signal with a modulation index.

(399) In some embodiments, the load is a primary load, and the plurality of instructions further cause the control circuitry to regulate voltage provided from the interconnection module to an auxiliary load. The plurality of instructions can further cause the control circuitry to control switch circuitry of the interconnection module to regulate the voltage supplied to the auxiliary load.

(400) In some embodiments, the plurality of instructions further cause the control circuitry to reduce net energy supplied from the energy source of the interconnection module to the first array. The plurality of instructions can further cause the control circuitry to cause the interconnection module to supply energy for both the first and second arrays during a balanced condition. The plurality of instructions can further cause the control circuitry to cause an increase of net energy output by at least one module of the first array. The increase in net energy is equivalent to the reduction in net energy. The plurality of instructions can further cause the control circuitry to increase net energy supplied by all modules of the first array. The plurality of instructions can further cause the control circuitry to cause relative amounts of net energy output from the interconnection module to the second array and from the modules of the second array to remain at a

constant level. The plurality of instructions can further cause the control circuitry to: increase net energy output from the interconnection module to the second array; and reduce net energy output by at least one module of the second array. The plurality of instructions can further cause the control circuitry to decrease a modulation index for switch circuitry of the interconnection module coupled to the first array in order to reduce net energy supplied from the energy source of the interconnection module to the first array.

(401) In some embodiments, the plurality of instructions further cause the control circuitry to determine or estimate energy output adjustments that cause the first and second array to converge to a balanced condition.

(402) In some embodiments, the plurality of instructions further cause the control circuitry to the unbalanced condition relates to state of charge, temperature, capacity, state of health, voltage, and/or current.

(403) In some embodiments, the plurality of instructions further cause the control circuitry to control the energy storage system to generate the first and second voltage waveforms according to a pulse width modulation or hysteresis technique.

(404) In some embodiments, the plurality of instructions further cause the control circuitry to cause the interconnection module to supply energy for both the first and second arrays during a balanced condition.

(405) In some embodiments, the plurality of instructions further cause the control circuitry to control the system to converge towards an inter-phase balanced condition by adjustment of modulation indexes of the system.

(406) In some embodiments, the plurality of instructions further cause the control circuitry to determine that the unbalanced condition exists between the first array and second array by reference to an SOC parameter of or characterizing one array that is less than, more than, or substantially different than an SOC parameter for at least one different array or the system as a whole.

(407) In some embodiments, the plurality of instructions further cause the control circuitry to determine that the unbalanced condition exists between the first array and second array by reference to a temperature parameter of or characterizing one array that is less than, more than, or substantially different than the temperature parameter for at least one different array or the system as a whole.

(408) In some embodiments, the plurality of instructions further cause the control circuitry to determine that the unbalanced condition exists between the first array and second array by reference to a fault or degradation condition.

(409) In some embodiments, the plurality of instructions further cause the control circuitry to use the interconnection module and neutral point shifting to control a balance of inter-phase energy between the first and second arrays.

(410) In some embodiments, the plurality of instructions further cause the control circuitry to: determine an amount of inter-phase imbalance between the first and second arrays; cause the interconnection module to adjust net energy output to decrease the amount of inter-phase imbalance if below a threshold; and cause a shift to a neutral point of the system to adjust net energy output to decrease the amount of interphase imbalance if above the threshold. The plurality of instructions can further cause the control circuitry to also use the interconnection module to adjust net energy output to decrease the amount of inter-phase imbalance if the amount of interphase imbalance is above the threshold.

(411) In some embodiments, the processing circuitry includes a plurality of processors and the memory includes a plurality of discrete memory devices.

(412) In many embodiments, a module-based energy system is provided, the system including: a first array of cascaded modules configured to output a first voltage waveform to a load; a second array of cascaded modules configured to output a second voltage waveform to the load; a third

array of cascaded modules configured to output a third voltage waveform to the load, where the first, second, and third voltage waveforms each have a different phase angle; a first interconnection module coupled to both the first array and the second array, where the first interconnection module includes a first energy source and first switch circuitry; and a second interconnection module coupled to the third array, where the second interconnection module includes a second energy source and second switch circuitry, where the first and second energy sources are electrically coupled together, and where the first interconnection module is configured to adjust the amount of energy supplied by the first and second energy sources to the first and/or second arrays, and where the second interconnection module is configured to adjust the amount of energy supplied by the first and second energy sources to the third array.

(413) In some embodiments, the first array and second array are positioned electrically between the load and the first interconnection module, and the third array is positioned electrically between the load and the second interconnection module.

(414) In some embodiments, the system further includes control circuitry configured to control the first and second switch circuitry, where the first energy source has a positive node and a negative node that are shared with the second energy source, and where the first switch circuitry is controllable to selectively couple the first and/or second arrays to the first and/or second nodes, and the second switch circuitry is controllable to selectively couple the third array to the first and/or second nodes. The control circuitry can be configured to control the first and second switch circuitry to adjust relative energy output from the first and second energy sources to one of the first, second, and third arrays to mitigate an imbalance of charge or temperature between at least two of the first, second, and third arrays. The control circuitry can be configured to control the balance of inter-phase energy between the first, second, and third arrays with a shift to a neutral point of the first, second, and third arrays. The control circuitry can be configured to control the first and second switch circuitry, under a balanced inter-phase condition, such that the first interconnection module supplies energy for both the first and second arrays and the second interconnection module supplies energy for the third array. The net energy supplied to the first, second, and third arrays can be the same for a period of time.

(415) In many embodiments, a module-based energy system is provided, the system including: a first battery pack including a first plurality of arrays of cascaded converter modules configured to output a first plurality of voltage waveforms to power a first motor, each of the first plurality of voltage waveforms having a different phase angle; a second battery pack including a second plurality of arrays of cascaded converter modules configured to output a second plurality of voltage waveforms to power a second motor, each of the second plurality of voltage waveforms having a different phase angle; and an interconnection module coupled to a first array of the first plurality of arrays and a second array of the second plurality of arrays, where the interconnection module includes an energy source and switch circuitry, where the interconnection module is configured to adjust the amount of energy supplied by the energy source to the first and/or second arrays.

(416) In some embodiments, the first battery pack includes a first housing, and the first plurality of arrays are co-located in the first housing, and where the second battery pack includes a second housing, and the second plurality of arrays are co-located in the second housing. The interconnection module can be located in the first housing.

(417) In some embodiments, the first and second motors are in-wheel motors of an electric vehicle.

(418) In many embodiments, the system further includes control circuitry configured to monitor operating parameters of the first and second battery packs and to cause the system to balance energy between the first battery pack and the second batter pack with the interconnection module. The control circuitry can be configured to control the switch circuitry such that the energy source discharges relatively more energy to the first array than to the second array under an unbalanced condition between the first and second arrays.

(419) In some embodiments, the interconnection module is a first interconnection module, the

energy source is a first energy source, and the switch circuitry is first switch circuitry, the system further including: a third battery pack including a third plurality of arrays of cascaded converter modules configured to output a third plurality of voltage waveforms to power a third motor, each of the third plurality of voltage waveforms having a different phase angle; a fourth battery pack including a fourth plurality of arrays of cascaded converter modules configured to output a fourth plurality of voltage waveforms to power a fourth motor, each of the fourth plurality of voltage waveforms having a different phase angle; and a second interconnection module coupled to a third array of the third plurality of arrays and a fourth array of the fourth plurality of arrays, where the second interconnection module includes a second energy source and second switch circuitry, where the second interconnection module is configured to adjust the amount of energy supplied by the second energy source to the third and/or fourth arrays. The first, second, third, and fourth motors can be in-wheel motors of a four wheel electric vehicle.

(420) Processing circuitry can include one or more processors, microprocessors, controllers, and/or microcontrollers, each of which can be a discrete or stand-alone chip or distributed amongst (and a portion of) a number of different chips. Any type of processing circuitry can be implemented, such as, but not limited to, personal computing architectures (e.g., such as used in desktop PC's, laptops, tablets, etc.), programmable gate array architectures, proprietary architectures, custom architectures, and others. Processing circuitry can include a digital signal processor, which can be implemented in hardware and/or software. Processing circuitry can execute software instructions stored on memory that cause processing circuitry to take a host of different actions and control other components.

(421) Processing circuitry can also perform other software and/or hardware routines. For example, processing circuitry can interface with communication circuitry and perform analog-to-digital conversions, encoding and decoding, other digital signal processing, multimedia functions, conversion of data into a format (e.g., in-phase and quadrature) suitable for provision to communication circuitry, and/or can cause communication circuitry to transmit the data (wired or wirelessly).

(422) Any and all signals described herein can be communicated wirelessly except where noted or logically implausible. Communication circuitry can be included for wireless communication. The communication circuitry can be implemented as one or more chips and/or components (e.g., transmitter, receiver, transceiver, and/or other communication circuitry) that perform wireless communications over links under the appropriate protocol (e.g., Wi-Fi, Bluetooth, Bluetooth Low Energy, Near Field Communication (NFC), Radio Frequency Identification (RFID), proprietary protocols, and others). One or more other antennas can be included with communication circuitry as needed to operate with the various protocols and circuits. In some embodiments, communication circuitry can share antenna for transmission over links. Processing circuitry can also interface with communication circuitry to perform the reverse functions necessary to receive a wireless transmission and convert it into digital data, voice, and/or video. RF communication circuitry can include a transmitter and a receiver (e.g., integrated as a transceiver) and associated encoder logic.

(423) Processing circuitry can also be adapted to execute the operating system and any software applications, and perform those other functions not related to the processing of communications transmitted and received.

(424) Computer program instructions for carrying out operations in accordance with the described subject matter may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, JavaScript, Smalltalk, C++, C #, Transact-SQL, XML, PHP or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages.

(425) Memory, storage, and/or computer readable media can be shared by one or more of the various functional units present, or can be distributed amongst two or more of them (e.g., as separate memories present within different chips). Memory can also be a separate chip of its own.

(426) To the extent the embodiments disclosed herein include or operate in association with memory, storage, and/or computer readable media, then that memory, storage, and/or computer readable media are non-transitory. Accordingly, to the extent that memory, storage, and/or computer readable media are covered by one or more claims, then that memory, storage, and/or computer readable media is only non-transitory. The terms "non-transitory" and "tangible" as used herein, are intended to describe memory, storage, and/or computer readable media excluding propagating electromagnetic signals, but are not intended to limit the type of memory, storage, and/or computer readable media in terms of the persistency of storage or otherwise. For example, "non-transitory" and/or "tangible" memory, storage, and/or computer readable media encompasses volatile and non-volatile media such as random access media (e.g., RAM, SRAM, DRAM, FRAM, etc.), read-only media (e.g., ROM, PROM, EPROM, EEPROM, flash, etc.) and combinations thereof (e.g., hybrid RAM and ROM, NVRAM, etc.) and variants thereof.

(427) It should be noted that all features, elements, components, functions, and steps described with respect to any embodiment provided herein are intended to be freely combinable and substitutable with those from any other embodiment. If a certain feature, element, component, function, or step is described with respect to only one embodiment, then it should be understood that that feature, element, component, function, or step can be used with every other embodiment described herein unless explicitly stated otherwise. This paragraph therefore serves as antecedent basis and written support for the introduction of claims, at any time, that combine features, elements, components, functions, and steps from different embodiments, or that substitute features, elements, components, functions, and steps from one embodiment with those of another, even if the following description does not explicitly state, in a particular instance, that such combinations or substitutions are possible. It is explicitly acknowledged that express recitation of every possible combination and substitution is overly burdensome, especially given that the permissibility of each and every such combination and substitution will be readily recognized by those of ordinary skill in the art.

(428) As used herein and in the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise.

(429) While the embodiments are susceptible to various modifications and alternative forms, specific examples thereof have been shown in the drawings and are herein described in detail. It should be understood, however, that these embodiments are not to be limited to the particular form disclosed, but to the contrary, these embodiments are to cover all modifications, equivalents, and alternatives falling within the spirit of the disclosure. Furthermore, any features, functions, steps, or elements of the embodiments may be recited in or added to the claims, as well as negative limitations that define the inventive scope of the claims by features, functions, steps, or elements that are not within that scope.

Claims

1. A module-based energy system, comprising: a first battery pack comprising a first plurality of arrays of cascaded converter modules configured to output a first plurality of AC voltage waveforms to power a first multi-phase motor, wherein: each of the cascaded converter modules in the first plurality of arrays comprises an energy source and is controllable to selectively output a respective output voltage; in each array of the first plurality of arrays, the cascaded converter modules are coupled together to output one of the first plurality of AC voltage waveforms comprising a superposition of the respective output voltages of that respective array; the first plurality of arrays of cascaded converter modules comprises first, second and third arrays of cascaded converter modules; a second battery pack comprising a second plurality of arrays of cascaded converter modules configured to output a second plurality of AC voltage waveforms to power a second multi-phase motor, wherein: each of the cascaded converter modules in the second

plurality of arrays comprises an energy source and is controllable to selectively output a respective output voltage; in each array of the second plurality of arrays, the cascaded converter modules are coupled together to output one of the second plurality of AC voltage waveforms comprising a superposition of the respective output voltages of that respective array; the second plurality of arrays of cascaded converter modules comprises first, second and third arrays of cascaded converter modules; and each respective array of the first plurality of arrays of the first battery pack is singly coupled to only a single respective array in the second plurality of arrays of the second battery pack by a series coupling of a first converter module in the respective array of the first plurality of arrays and a first converter module in the respective array of the second plurality of arrays such that energy can be transferred between the respective array of the first plurality of arrays and the respective array of the second plurality of arrays; and control circuitry coupled to each array of the first plurality of arrays and each array of the second plurality of arrays, the control circuitry configured to monitor one or more operating parameters of the cascaded converter modules in the first plurality of arrays and the second plurality of arrays and generate control signals that cause transfer of energy between the respective arrays of the first plurality of arrays and the respective arrays of the second plurality of arrays.

2. The module-based energy system of claim 1, further comprising: a first energy source coupled to a first array of the first plurality of arrays and a first array of the second plurality of arrays; a second energy source coupled to a second array of the first plurality of arrays and a second array of the second plurality of arrays; and a third energy source coupled to a third array of the first plurality of arrays and a third array of the second plurality of arrays; wherein the control circuitry is configured to: detect an unbalanced condition between the first plurality of arrays and the second plurality of arrays; and in response to detecting the unbalanced condition, generate control signals that cause a respective energy source coupled to respective arrays in the first plurality of arrays and the second plurality of arrays to discharge different amounts of energy to the respective arrays.

3. The module-based energy system of claim 2, wherein the control circuitry is further configured to generate a respective modulation index for each of the first energy source, second source, and third energy source, wherein each modulation index controls the discharge of the different amounts of energy to the respective arrays.

4. The module-based energy system of claim 2, wherein the unbalanced condition comprises at least one of (i) the first plurality of arrays having a lower overall energy level than the second plurality of arrays or (ii) the first array of the first plurality of arrays to which the energy source is coupled has a lower overall energy level than the first array of the second plurality of arrays to which the energy source is coupled.

5. The module-based energy system of claim 2, wherein the unbalanced condition comprises (i) a difference in charge, temperature, capacity, state of health, voltage, and/or current between the first plurality of arrays and the second plurality of arrays and/or (ii) a difference in charge, temperature, capacity, state of health, voltage, and/or current between the first array of the first plurality of arrays to which the energy source is coupled and the first array of the second plurality of arrays to which the energy source is coupled.

6. The module-based energy system of claim 1, wherein: each array of the first plurality of arrays and each array of the second plurality of arrays have a same quantity of cascaded converter modules; all cascaded modules of each array of the first plurality of arrays are series connected to a respective phase of the first multi-phase motor; and all cascaded modules of each array of the second plurality of arrays are series connected to a respective phase of the second multi-phase motor.

7. The module-based energy system of claim 1, wherein: the first battery pack comprises a first housing, and the first plurality of arrays are co-located in the first housing; the second battery pack comprises a second housing, and the second plurality of arrays are co-located in the second housing; and the first housing is different from the second housing.

8. The module-based energy system of claim 1, wherein the first multi-phase motor and the second multi-phase motor are drive motors of an electric vehicle.

9. The module-based energy system of claim 1, wherein at least one of the first voltage and first frequency is different from at least one of the second voltage and second frequency.

10. The module-based energy system of claim 1, wherein the module-based energy system comprises a connection to supply auxiliary power to an auxiliary power load, wherein the connection is located in a position between a respective one of the first plurality of arrays and a respective one of the second plurality of arrays.

11. The module-based energy system of claim 1, wherein the control circuitry is configured to generate control signals that cause transfer of energy between a respective array of the first plurality of arrays and a respective array of the second plurality of arrays with neutral point shifting.

12. A method of transferring energy in a system comprising a first battery pack comprising a first plurality of arrays of cascaded converter modules configured to output a first plurality of AC voltage waveforms to power a first multi-phase motor and a second battery pack comprising a second plurality of arrays of cascaded converter modules configured to output a second plurality of AC voltage waveforms to power a second multi-phase motor, wherein each cascade converter includes an energy source and is controllable to selectively output a respective output voltage, the method comprising: respectively connecting the first plurality of arrays of the first battery pack to the second plurality of arrays of the second battery pack in respective series connections such that each respective array in the first plurality of arrays is connected to only a single respective array in the second plurality of arrays so that energy can be transferred between the respectively connected arrays of the first plurality of arrays and a respective array of the second plurality of arrays; and monitoring one or more operating parameters of the cascaded converter modules in the first plurality of arrays and the second plurality of arrays; based on the monitoring of the one or more operating parameters, generating control signals for control circuitry that cause the transfer of energy between the respective arrays of the first plurality of arrays and the respective arrays of the second plurality of arrays.

13. The method of claim 12, further comprising: detecting an unbalanced condition between the first plurality of arrays and the second plurality of arrays; and in response to detecting the unbalanced condition, generating control signals that cause a respective energy source coupled to respective arrays in the first plurality of arrays and the second plurality of arrays to discharge different amounts of energy to the respective arrays.

14. The method of claim 13, further comprising generating a respective modulation index for each of the energy sources, wherein each modulation index controls the discharge of the different amounts of energy to the respective arrays.

15. The method of claim 13, wherein the unbalanced condition comprises at least one of (i) the first plurality of arrays having a lower overall energy level than the second plurality of arrays or (ii) the first array of the first plurality of arrays to which the energy source is coupled has a lower overall energy level than the first array of the second plurality of arrays to which the energy source is coupled.

16. The method of claim 13, wherein the unbalanced condition comprises (i) a difference in charge, temperature, capacity, state of health, voltage, and/or current between the first plurality of arrays and the second plurality of arrays and/or (ii) a difference in charge, temperature, capacity, state of health, voltage, and/or current between the first array of the first plurality of arrays to which the energy source is coupled and the first array of the second plurality of arrays to which the energy source is coupled.

17. The method of claim 12 further comprising generating control signals that cause the transfer of energy between the respective array of the first plurality of arrays and the respective array of the second plurality of arrays with neutral point shifting.