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(71) Applicant: **BLOOM ENERGY CORPORATION**
[US/US]; 4353 North First Street, San Jose, California
95134 (US).

(72) Inventors: **COTTULI, Carl**; c/o BLOOM ENERGY
CORPORATION, 4353 North First Street, San Jose, Cal-
ifornia 95134 (US). **GOPINATH, Rajesh**; c/o BLOOM

ENERGY CORPORATION, 4353 North First Street, San
Jose, California 95134 (US).

(74) Agent: **RADOMSKY, Leon** et al.; The Marbury Law
Group, PLLC, 11800 Sunrise Valley Drive, 15th Floor, Re-
ston, Virginia 20191 (US).

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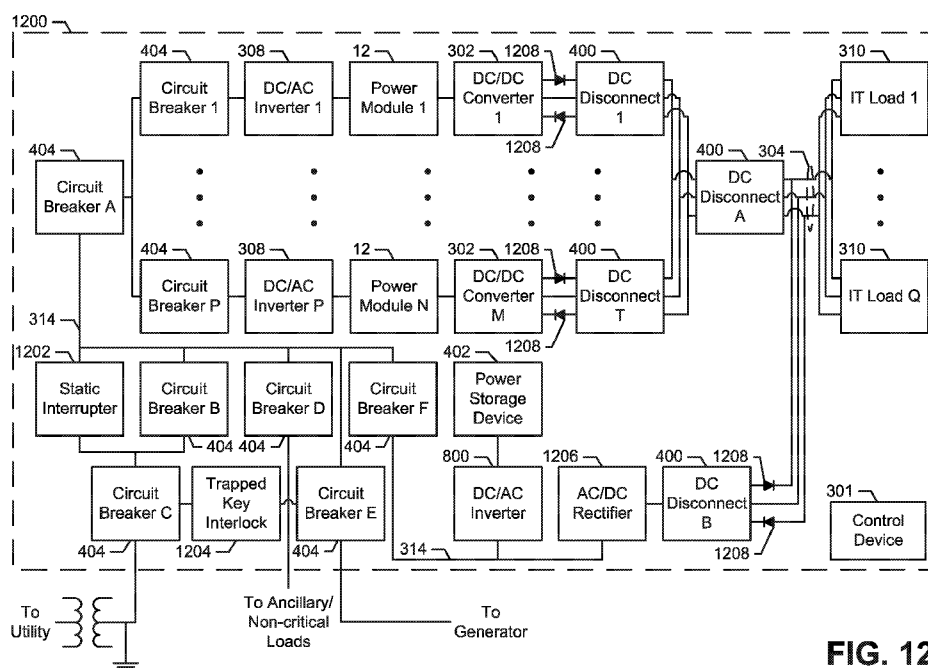


FIG. 12

(57) Abstract: A method of operating a power generation system, such as a fuel cell power generation system, includes providing a first electrical power up to a threshold amount of power to a load from at least one power module via a plurality of DC/DC converters and a DC power bus, determining whether electrical power from a utility is available, and providing a second electrical power from the at least one power module to a rectifier path via a plurality of DC/AC inverters in response to determining that the electrical power from the utility is available. The second electrical power includes electrical power generated by the at least one power module in excess of the threshold amount of electrical power.

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TITLE**Hybrid DC Power Installation For Data Center Load****RELATED APPLICATIONS**

[0001] This application claims the benefit of priority to U.S. Provisional Patent Application Ser. No. 62/808,127 entitled “Hybrid DC Power Installation For Data Center Load” filed on February 20, 2019. The entire contents this document are incorporated herein by reference for all purposes.

FIELD

[0002] The present invention is generally directed to power generation systems and, in particular, to a fuel cell system that efficiently manages fuel cell power output that exceeds a load power demand.

BACKGROUND

[0003] Electrochemical devices, such as fuel cells, can convert energy stored in fuels to electrical energy with high efficiencies. In a fuel cell system, such as a solid oxide fuel cell (SOFC) system, an oxidizing flow is passed through the cathode side of the fuel cell while a fuel inlet flow is passed through the anode side of the fuel cell. The oxidizing flow is typically air, while the fuel flow can be a hydrocarbon fuel, such as methane, natural gas, pentane, ethanol, or methanol. The fuel cell enables the transport of negatively charged oxygen ions from the cathode flow stream to the anode flow stream, where the ion combines with either free hydrogen or hydrogen in a hydrocarbon molecule to form water vapor and/or with carbon monoxide to form carbon dioxide. The excess electrons from the negatively charged ion are routed back to the cathode side of the fuel cell through an electrical circuit completed between anode and cathode, resulting in an electrical current flow through the circuit.

[0004] SOFC systems may be used to power many different devices under many different arrangements. The variety of potential applications creates a need for an SOFC system and control method that can be readily adapted for use with different kinds of systems using different control hardware and software.

SUMMARY

[0005] One embodiment includes a method of operating a power generation system, such as a fuel cell power generation system, includes providing a first electrical power up to a threshold amount of power to a load from at least one power module via a plurality of DC/DC converters and a DC power bus, determining whether electrical power from a utility is available, and providing a second electrical power from the at least one power module to a rectifier path via a plurality of DC/AC inverters in response to determining that the electrical power from the utility is available. The second electrical power includes electrical power generated by the at least one power module in excess of the threshold amount of electrical power.

[0006] Another embodiment includes a system, comprising a plurality of power modules each including at least one fuel cell, a plurality of direct current (DC)/DC converters each having an input end and an output end, and each electrically connected to a power module of the plurality of power modules at the input end, a DC power bus electrically connected to the plurality of DC/DC converters in parallel at the output end and electrically connectable to a load, a plurality of DC/alternating current (AC) inverters each having a DC end and an AC end, and each electrically connected to a power module of the plurality of power modules at the DC end, a rectifier path electrically connected to the plurality of DC/AC inverters at the AC end in parallel, an AC/DC rectifier having an AC end and a DC end, and electrically connected to the rectifier path at the AC end and to the DC power bus at the DC end, and a control device communicatively connected to the plurality of DC/DC converters and to the plurality of DC/AC inverters. The control device is configured with control device executable instructions to cause the control device to provide a first electrical power up to a threshold amount of power to the load from the plurality of power modules via the plurality of DC/DC converters and the DC power bus, determine whether electrical power from a utility is available, and provide a second electrical power from the plurality of power modules to the rectifier path via the plurality of DC/AC inverters in response to determining that the electrical power from the utility is available, wherein the second electrical power comprises electrical power generated by the plurality of power modules in excess of the threshold amount of electrical power.

[0007] Another embodiment includes a fuel cell system, comprising a plurality of power modules each including at least one fuel cell, a plurality of direct current (DC)/DC converters

each having an input end and an output end, and each electrically connected to a power module of the plurality of power modules at the input end, a DC power bus electrically connected to the plurality of DC/DC converters in parallel at the output end and electrically connectable to a load, a plurality of DC/alternating current (AC) inverters each having a DC end and an AC end, and each electrically connected to a power module of the plurality of power modules at the DC end, an AC bus electrically connected to the plurality of DC/AC inverters at the AC end in parallel, a bidirectional DC/AC inverter having a DC end and an AC end, and electrically connected to the AC bus at the AC end, a power storage device electrically connected to the bidirectional DC/AC inverter at the DC end, and an AC/DC rectifier having an AC end and a DC end, and electrically connected to the AC bus at the AC end and to the DC power bus at the DC end.

DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a perspective view of a fuel cell system according to various embodiments.

[0009] FIG. 2 is a schematic side cross-sectional view of a hot box according to various embodiments.

[0010] FIG. 3A is a block diagram of a fuel cell information technology (IT) grid system according to some embodiments.

[0011] FIG. 3B is a block diagram of a fuel cell IT grid system according to some embodiments.

[0012] FIG. 3C is a block diagram of a fuel cell IT grid system according to some embodiments.

[0013] FIG. 3D is a block diagram of a fuel cell IT grid system according to some embodiments.

[0014] FIG. 3E is a block diagram of a plurality of fuel cell IT grid systems according to some embodiments.

[0015] FIG. 4 is a block diagram of a fuel cell IT grid system according to some embodiments.

[0016] FIG. 5 is a block diagram of a fuel cell IT grid system according to some embodiments.

[0017] FIG. 6 is a block diagram of a fuel cell IT grid system according to some embodiments.

[0018] FIG. 7 is a block diagram of a fuel cell IT grid system according to some embodiments.

[0019] FIG. 8 is a block diagram of a fuel cell IT grid system according to some embodiments.

[0020] FIG. 9 is a block diagram of a fuel cell IT grid system according to some embodiments.

[0021] FIG. 10 is a block diagram of a fuel cell IT grid system according to some embodiments.

[0022] FIG. 11 is a process flow diagram for managing a fuel cell IT grid system according to some embodiments.

[0023] FIG. 12 is block diagram of a fuel cell IT grid system according to some embodiments.

[0024] FIG. 13 is a schematic diagram of a static interrupter according to some embodiments.

[0025] FIG. 14 is a process flow diagram for managing hybrid DC power to a load according to some embodiments.

[0026] FIGS. 15A and 15B are process flow diagrams for normal mode management of hybrid DC power to a load according to some embodiments.

[0027] FIG. 16 is a process flow diagram for fail mode management of hybrid DC power to a load according to some embodiments.

DETAILED DESCRIPTION

[0028] The various embodiments will be described in detail with reference to the accompanying drawings. Wherever possible, the same reference numbers will be used

throughout the drawings to refer to the same or like parts. References made to particular examples and implementations are for illustrative purposes, and are not intended to limit the scope of the claims.

[0029] Various embodiments include electrical circuits, electrical components, and methods for managing the cycling of fuel cells in a fuel cell grid system. Fuel cell performance and longevity may be managed and improved by maintaining fuel cell operation at certain outputs, thereby reducing the amount and frequency of heat cycling fuel cells. Temperature of a fuel cell may be correlated to an amount of electrical output generated by the fuel cell. A temperature threshold may be set at a temperature at which fatigue or damage to components of the fuel cell may occur from thermal cycling from below to above the temperature threshold. Repeatedly reheating the fuel cell from temperatures below the temperature threshold to temperatures above the temperature threshold when generating electrical output may compound the fatigue or damage to components of the fuel cell.

[0030] Operating a fuel cell at a steady electrical output may maintain the temperature of the fuel cell above the temperature threshold and thus reduce the amount and frequency of thermal cycling below the temperature threshold. However, the electrical power demand by a load varies, and thus when the fuel cell is deployed in a fuel cell grid system the electrical output generated by the fuel cell may drop below the level required to maintain the fuel cell temperature at or above the temperature threshold. Thus, operating a fuel cell in a grid system may generate more electrical power than can be consumed by the system. While storing excess power in batteries is an option, such batteries may be an expensive complication to the system and may be unable to store all of the excess power during some periods.

[0031] In various embodiments a load may be any electrical device that consumes electrical power to operate. Loads may include electrical devices for residential, office, industrial, and/or service applications, including electrical devices for lighting, environmental control, machinery, data processing and storage, etc. In the instant application information technology (IT) applications are used as an illustrative example, and do not limit the claims and descriptions to IT application. The term “IT load” as used herein as an illustrative example may be substituted for any type of load in various embodiments. The term “fuel cell IT grid system” may refer to an example full cell grid system incorporating the example IT load, and may be substituted for any fuel cell grid system incorporating any type of load.

[0032] Various embodiments may include a load balancing load that is electrically connected to the fuel cell grid system with connections to the load regulated to accept excess power to enable fuel cells to operate at sufficient power to remain above the threshold temperature. The fuel cell grid system may direct to the load balancing load any electrical power generated by the fuel cell in excess of the electrical power demanded by the load and/or a storage capacity in the fuel cell grid system. In various embodiments, the load balancing load may include any electricity consuming or storing device or system. For example, the load balancing load may include a load bank load located within or near the fuel cell grid system configured to dissipate the excess power. As another example, the load balancing load may include a mechanical load located within or near the fuel cell grid system, such as a cooling system. As another example, the load balancing load may include an electrical load of the fuel cell grid system, such as a lighting system. As another example, the load balancing load may include an electrical storage unit located within or near the fuel cell grid system. As another example, the load balancing load may include an electrical load located remotely from the fuel cell grid system, such as an electrical utility grid. In various embodiments, the load balancing load may include multiple of the same type of load balancing load or any combination of various types of load balancing loads.

[0033] FIG. 1 illustrates an example of modular fuel cell system that is more fully described in U.S. Patent Number 8,440,362, incorporated herein by reference for descriptions of the modular fuel cell system. The modular system may contain modules and components described above as well as in U.S. Patent Publication No. US 2011-0281185 (Application Serial Number 11/656,006, filed on January 22, 2007), which is incorporated herein by reference for descriptions of the modular fuel cell system. The modular design of the fuel cell system enclosure 10 provides flexible system installation and operation.

[0034] The modular fuel cell system enclosure 10 includes a plurality of power module housings 12 (containing a fuel cell power module components), one or more fuel input (i.e., fuel processing) module housings 16, and one or more power conditioning (i.e., electrical output) module housings 18. For example, the system enclosure may include any desired number of modules, such as 2-30 power modules, for example 6-12 power modules. FIG. 1 illustrates a system enclosure 10 containing six power modules (one row of six modules stacked side to side), one fuel processing module, and one power conditioning module, on a common base 20. Each module may comprise its own cabinet or housing. Alternatively, the

power conditioning and fuel processing modules may be combined into a single input/output module located in one cabinet or housing 14. For brevity, each housing 12, 14, 16, 18 will be referred to as “module” below.

[0035] While one row of power modules 12 is shown, the system may comprise more than one row of modules 12. For example, the system may comprise two rows of power modules stacked back to back.

[0036] Each power module 12 is configured to house one or more hot boxes 13. Each hot box contains one or more stacks or columns of fuel cells (not shown for clarity), such as one or more stacks or columns of solid oxide fuel cells having a ceramic oxide electrolyte separated by conductive interconnect plates. Other fuel cell types, such as PEM, molten carbonate, phosphoric acid, etc. may also be used.

[0037] The modular fuel cell system enclosure 10 also contains one or more input or fuel processing modules 16. This module 16 includes a cabinet which contains the components used for pre-processing of fuel, such as desulfurizer beds. The fuel processing modules 16 may be designed to process different types of fuel. For example, a diesel fuel processing module, a natural gas fuel processing module, and an ethanol fuel processing module may be provided in the same or in separate cabinets. A different bed composition tailored for a particular fuel may be provided in each module. The processing module(s) 16 may process at least one of the following fuels selected from natural gas provided from a pipeline, compressed natural gas, methane, propane, liquid petroleum gas, gasoline, diesel, home heating oil, kerosene, JP-5, JP-8, aviation fuel, hydrogen, ammonia, ethanol, methanol, syn-gas, bio-gas, bio-diesel and other suitable hydrocarbon or hydrogen containing fuels. If desired, a reformer 17 may be located in the fuel processing module 16. Alternatively, if it is desirable to thermally integrate the reformer 17 with the fuel cell stack(s), then a separate reformer 17 may be located in each hot box 13 in a respective power module 12. Furthermore, if internally reforming fuel cells are used, then an external reformer 17 may be omitted entirely.

[0038] The modular fuel cell system enclosure 10 also contains one or more power conditioning modules 18. The power conditioning module 18 includes a cabinet which contains the components for converting the fuel cell stack generated DC power to AC power, electrical connectors for AC power output to the grid, circuits for managing electrical

transients, a system controller (e.g., a computer or dedicated control logic device or circuit). The power conditioning module 18 may be designed to convert DC power from the fuel cell modules to different AC voltages and frequencies. Designs for 208V, 60Hz; 480V, 60Hz; 415V, 50Hz and other common voltages and frequencies may be provided.

[0039] The fuel processing module 16 and the power conditioning module 18 may be housed in one input/output cabinet 14. If a single input/output cabinet 14 is provided, then modules 16 and 18 may be located vertically (e.g., power conditioning module 18 components above the fuel processing module 16 desulfurizer canisters / beds) or side by side in the cabinet 14.

[0040] As shown in an example embodiment in FIG. 1, one input/output cabinet 14 is provided for one row of six power modules 12, which are arranged linearly side to side on one side of the input/output module 14. The row of modules may be positioned, for example, adjacent to a building for which the system provides power (e.g., with the backs of the cabinets of the modules facing the building wall). While one row of power modules 12 is shown, the system may include more than one row of modules 12. For example, as noted above, the system may include two rows of power modules stacked back to back.

[0041] Each of the power modules 12 and input/output modules 14 include a door 30 (e.g., hatch, access panel, etc.) to allow the internal components of the module to be accessed (e.g., for maintenance, repair, replacement, etc.). According to one embodiment, the modules 12 and 14 are arranged in a linear array that has doors 30 only on one face of each cabinet, allowing a continuous row of systems to be installed abutted against each other at the ends. In this way, the size and capacity of the fuel cell enclosure 10 can be adjusted with additional modules 12 or 14 and bases 20 with minimal rearranging needed for existing modules 12 and 14 and bases 20. If desired, the door 30 to module 14 may be on the side rather than on the front of the cabinet.

[0042] FIG. 2 illustrates a plan view of a fuel cell system hotbox 13 including a fuel cell stack or column 40. The hotbox 13 is shown to include the fuel cell stack or column 40. However, the hotbox 13 may include two or more of the stacks or columns 40. The stack or column 40 may include the electrically connected fuel cells 45 stacked on one another, with the interconnects 50 disposed between the fuel cells 45. The first and last fuel cells 45 in the stack or column are disposed between a respective end plate 60 and interconnect 50. The end plates 60 are electrically connected to electrical outputs of the fuel cell stack or column 40.

The hotbox 13 may include other components, such as fuel conduits, air conduits, seals, electrical contacts, etc, and may be incorporated into a fuel cell system including balance of plant components. The fuel cells 45 may be solid oxide fuel cells containing a ceramic electrolyte, such as yttria stabilized zirconia (YSZ) or scandia stabilized zirconia (SSZ), an anode electrode, such as a nickel-YSZ, a Ni-SSZ or a nickel-samarium doped ceria (SDC) cermet, and a cathode electrode, such as lanthanum strontium manganite (LSM)). The interconnects 50 and/or end plates 60 may comprise any suitable gas impermeable and electrically conductive material, such as a chromium – iron alloy, such as an alloy containing 4 to 6 wt% iron and balance chromium. The interconnects 50 electrically connect adjacent fuel cells 45 and provide channels for fuel and air to reach the fuel cells 45.

[0043] Fuel cell systems, such as modular fuel cell system enclosure 10, may include and/or be augmented by various pieces of support equipment. Support equipment may include various auxiliary equipment and systems to support the operation of the fuel cell system. Support equipment may vary based on constraints and/or features at a site where the fuel cell system is installed. As non-limiting examples, support equipment may include, fuel support equipment, air support equipment, and/or ventilation support equipment. One type of fuel support equipment may include equipment configured to control supply and/or exhaust fuel pressure in the fuel cell system, such as a fuel blower or pump to supply fuel to, recycle fuel/exhaust in, and/or exhaust fuel from the fuel cell system. Another type of fuel support equipment may be configured to process fuel for the fuel cell system, such as a fuel pre-heater, exhaust scrubber, etc. Other types of fuel support equipment may also be used. One type of air support equipment may be air supply equipment configured to provide air into the fuel cell system and/or exhaust air from the fuel cell system, such as blowers or fans to provide air to and/or exhaust air from a fuel cell cathode, an anode tail gas oxidizer (ATO), an air heat exchanger, a CPOx reactor, etc. Other types of air support equipment may also be used. One type of ventilation support equipment may include equipment configured to ventilate from and/or circulate air in portions of housings external of the hot box (e.g., portions within modular fuel cell system enclosure 10 but external of the hot box 13 itself), such as a ventilation fan 80 to blow air from within the enclosure 10 out of the enclosure 10 to maintain an acceptable enclosure 10 pressure. Other types of ventilation support equipment may also be used. Support equipment, especially support equipment including electric motors may require Alternating Current (AC) power, for example one, two, or three phase AC power, for operation.

[0044] There may be several applications of fuel cell systems, such as modular fuel cell system enclosure 10, that require support equipment for the fuel cell systems to be powered in different modes. One mode may be a start up mode. In a start up mode, the fuel cell system may not yet be capable of producing power and the support equipment may be powered by a source other than the fuel cell system, such as the grid or another start up power source.

[0045] Another mode may be a normal operation mode. In a normal operation mode the fuel cell system may supply power to the support equipment, and grid or start up power sources may also supply power or be capable of supplying power to the support equipment. In an embodiment, in normal operation mode, the parasitic load of the support equipment may be powered directly from the fuel cell system. The powering of the support equipment by the fuel cell system may be an efficient mode of operation. Additionally, in the event of a grid or start up power source failure, the support equipment may already be powered by the fuel cell system and thus no interruption may occur in the support equipment operation.

[0046] Another mode may be stand alone mode in which only power from the fuel cell system is available to the support equipment. An additional mode may be a failure mode occurring when power is not available to the support equipment, such as a grid or start up power source outage during the start up mode or a fuel cell system failure during the stand alone mode.

[0047] FIGS. 3A-10 illustrate various embodiments of a fuel cell IT grid system 300 electrically connected to varying numbers and combinations of load balancing loads 306, which may also be referred to herein as a mechanical load 600 or an electrical utility grid 802 of an electric utility provider in non-limiting examples. A fuel cell IT grid system 300 may include a variety of components, including one or more control devices 301 configured to receive data signals from and send control signals to any number and combination of power modules 12, a DC/DC converter 302, a DC power bus 304, a DC/AC inverter 308, and an IT load 310 configured to operate using AC electrical current. In various embodiments of the fuel cell IT grid system 300, the IT load 310 may be configured to operate using DC electrical current, and the DC/AC inverter 308 may be omitted from the fuel cell IT grid system 300. The control device(s) 301 may be any form of programmable computing device or system, such as a server or overall system control device 301, that is configured to perform operations of various embodiments, including operations of the method illustrated in FIG. 11.

FIGS. 3A-10 illustrate various embodiments that are meant to be illustrative examples and not limiting of the scope of the claims.

[0048] A fuel cell IT grid system 300 may include any number “N” of power modules 12 that may be configured as described herein with reference to FIG. 1. In various embodiments, the number of power modules 12 may be at least as many power modules 12 necessary to generate sufficient electrical power to satisfy at least normal electrical power demands of an IT load 310. In various embodiments, the number of power modules 12 may include any number of redundant power modules 12 so that in case of reduced or no electrical output from at least one power module 12, a redundant power module 12 may be used to continue supply of the electrical power demand of the IT load 310. Similarly, a power module may include a redundant fuel cell stack (not shown) so that in case of reduced or no electrical output from at least one fuel cell stack of a power module 12, a redundant fuel cell stack may be used to continue supply of the electrical power demand of the IT load 310.

[0049] The power module 12 may be configured in a manner in which the power module 12 has a temperature threshold at which fatigue or damage the components of the power module 12 from repeatedly cycling components of the power module 12 from temperatures below the threshold to temperatures above the temperature threshold. In various embodiments, a power module 12 may be controlled to maintain a temperature above the temperature threshold. Control of a power module 12 to maintain a temperature above the temperature threshold may be based on temperature readings of components of the power module 12 and/or an electrical output of the power module 12. In various embodiments, a power module 12 may include a control device 301 configured to control the power module 12 to maintain a temperature above the temperature threshold. In various embodiments, control device 301 may be communicatively connected to any number of power modules 12 and configured to control each of the power modules 12 to maintain respective temperatures above the temperature threshold.

[0050] A power module 12 may be electrically connected to a DC/DC converter 302, and may supply a DC electrical current to the DC/DC converter 302 via an electrical conduit. The DC/DC converter 302 may be configured to convert a DC electrical current received from an electrical power source to a higher or lower voltage. A DC/DC converter 302 may be unidirectional, configured to receive electrical power at an input end and to supply electrical power at an output end. In various embodiments, the electrical power source may

include a power module 12. A DC/DC converter 302 may be electrically connected at an input end to a power module 12 and electrically connected to a DC power bus 304 at an output end. A DC electrical current received by a DC/DC converter 302 from a power module 12 may be converted by the DC/DC converter 302 and supplied to a DC power bus 304. In various embodiments, a DC/DC converter 302 may be configured to supply a designated voltage and/or amperage electrical power based on electrical power capacity of a fuel cell IT grid system 300 and/or an electrical power demand of IT loads 310. A designated voltage and/or amperage electrical power supplied by a DC/DC converter 302 may be based on voltage and/or amperage electrical power supplied by other DC/DC converter 302 or on a DC power bus 304. A fuel cell IT grid system 300 may include any number “M” of DC/DC converters 302 disposed between N power modules 12 and a DC power bus 304. In various embodiments, a fuel cell IT grid system 300 may include a one-to-one ratio of power modules 12 to DC/DC converters 302. In various embodiments, a fuel cell IT grid system 300 may include a one-to-many ratio of power modules 12 to DC/DC converters 302.

[0051] A DC power bus 304 may be configured as a common electrical conduit for multiple electrical power sources. In various embodiments, the electrical power sources may include any number and combination of a power modules 12, a power storage device 402, and/or an electrical utility grid 802. A DC power bus 304 may be electrically connected to electrical power sources via other components of a fuel cell IT grid system 300, such as DC/DC converters 302, DC disconnects 400, and/or bidirectional DC/AC inverters 800. A DC power bus 304 may be configured to transmit electrical power to a load. In various embodiments, the load may include any number and combination of an IT load 310 and a load balancing load 306. A DC power bus 304 may be electrically connected to multiple IT loads 310 via other components of a fuel cell IT grid system 300, such as DC/AC inverters 308.

[0052] A DC/AC inverter 308 may be configured to invert a DC electrical current received from an electrical power source to an AC electrical current. A DC/AC inverter 308 may be unidirectional, configured to receive electrical power at an input end and to supply electrical power at an output end. In various embodiments, the electrical power source may include any number and combination of a power module 12, a power storage device 402, and/or an electrical utility grid 802. A DC/AC inverter 308 may be electrically connected at an input end to an electrical power source and electrically connected to an IT load 310 at an output end. A DC/AC inverter 308 may be electrically connected to an electrical power source via

other components of a fuel cell IT grid system 300, such as a DC power bus 304, a DC/DC converter 302, and/or a bidirectional DC/AC inverter 800. A DC electrical current received by a DC/AC inverter 308 from an electrical power source may be inverted by the DC/AC inverter 308 and supplied to an IT load 310. In various embodiments, a DC/AC inverter 308 may be configured to supply a designated voltage and/or amperage electrical power based on electrical power configuration of an IT load 310 and/or an electrical power demand of the IT load 310. A fuel cell IT grid system 300 may include any number “P” of DC/AC inverters 308, each disposed between a DC power bus 304 and an IT load 310. In various embodiments, a fuel cell IT grid system 300 may include a one-to-one ratio of DC/AC inverters 308 to IT loads 310. In various embodiments, a fuel cell IT grid system 300 may include a one-to-many ratio of DC/AC inverters 308 to IT loads 310.

[0053] An IT load 310 may be configured to consume electrical power in a fuel cell IT grid system 300. In various embodiments, electrical power may be provided to a fuel cell IT grid system 300 by any number and combination of a power modules 12, a power storage device 402, and/or an electrical utility grid 802. An IT load 310 may include any number and combination of computing devices, such as servers, network switches, routers, supercomputers, and/or quantum computers. A fuel cell IT grid system 300 may include any number “Q” of IT loads 310. A voltage and/or amperage of electrical power required by an IT load 310 may be an electrical power demand of an IT load 310 on a fuel cell IT grid system 300. Multiple IT loads 310 require voltage and/or amperage of electrical power to be within specific requirements, and combined these requirements present the electrical power demand of the IT load 310 on a fuel cell IT grid system 300.

[0054] A load balancing load 306 may be configured to receive electrical power generated in a fuel cell IT grid system 300 beyond an electrical power demand of an IT load 310. In some embodiments, a load balancing load 306 may be configured to consume electrical power generated in a fuel cell IT grid system 300 beyond an electrical power demand of an IT load 310. In some embodiments, a load balancing load 306 may be configured to store and distribute an electrical power generated in a fuel cell IT grid system 300 beyond an electrical power demand of an IT load 310. A load balancing load 306 may include any number and combination of a load bank, a mechanical load 600, an electrical load, and/or a power storage device. A load bank may include any form of load bank configured to dissipate energy, such as by dissipating electrical power as heat energy, including a resistive load bank, an inductive

load bank, a capacitive load bank, and/or a combined load bank. A mechanical load 600 may include, for example, an IT load cooling system, an HVAC system, a gas and/or liquid pumping system, a fan, a vent, etc. An electrical load may include, for example, a lighting system, a security system, etc. A power storage device may include any form of power storage including electromagnetic power storage, mechanical power storage, electrochemical power storage, chemical power storage, and/or thermal power storage.

[0055] FIG. 3A illustrates an example of a fuel cell IT grid system 300 electrically connected to varying numbers and combinations of load balancing loads 306. The fuel cell IT grid system 300 may include N number of power modules 12. The power modules 12 may be electrically connected in parallel to a DC power bus 304. The fuel cell IT grid system 300 may include M number of DC/DC converters 302. Each power module 12 may be electrically connected to a DC/DC converter 302. The fuel cell IT grid system 300 may include a one-to-one ratio of power modules 12 to DC/DC converters 302. The DC/DC converters 302 may be electrically connected in parallel to the DC power bus 304. Each DC/DC converter 302 may be electrically connected between a power module 12 and the DC power bus 304.

[0056] The fuel cell IT grid system 300 may include Q number of IT loads 310. The IT loads 310 may be electrically connected in parallel to the DC power bus 304. In various embodiments, the electrical connection between an IT load 310 and the DC power bus 304 may be dual corded, which may increase reliability of electrical power supply from the DC power bus 304 to the IT load 310 by providing redundant electrical connections. The fuel cell IT grid system 300 may include P number of DC/AC inverters 308. Each IT load 310 may be electrically connected to a DC/AC inverter 308. In various embodiments, the dual corded electrical connection between an IT load 310 and the DC power bus 304 may be dual corded between an IT load 310 and an associated DC/AC inverter 308, which may increase reliability of electrical power supply from the associated DC/AC inverter 308 to the IT load 310 by providing redundant electrical connections. The fuel cell IT grid system 300 may include a one-to-one ratio of IT loads 310 to DC/AC inverters 308. The DC/AC inverters 308 may be electrically connected in parallel to the DC power bus 304. Each DC/AC inverters 308 may be electrically connected between an IT load 310 and the DC power bus 304.

[0057] The fuel cell IT grid system 300 may be electrically connected to any number or combination of load balancing loads 306. The fuel cell IT grid system 300 may be electrically connected to a load balancing load 306 via the DC power bus 304. The load balancing load 306 may receive excess electrical power in the fuel cell IT grid system 300, generated by a combination of the power modules 12, beyond the electrical power demand of the IT loads 310. The fuel cell IT grid system 300 may include a control device 301 configured to control connections to the load balancing load 306 to implement methods of various embodiments.

[0058] FIG. 3B illustrates an example of a fuel cell IT grid system 300 electrically connected to varying numbers and combinations of load balancing loads 306. The fuel cell IT grid system 300 may include N number of power modules 12. The power modules 12 may be electrically connected in parallel to multiple DC power busses 304. The fuel cell IT grid system 300 may include M number of DC/DC converters 302. Each power module 12 may be electrically connected to multiple DC/DC converters 302. The fuel cell IT grid system 300 may include a one-to-many ratio of power modules 12 to DC/DC converters 302. The DC/DC converters 302 may be electrically connected in parallel to the DC power busses 304. In various embodiments, a first DC/DC converter 302 electrically connected to a power module 12 may be electrically connected to a first DC power bus 304, and a second DC/DC converter 302 electrically connected to the power module 12 may be electrically connected to a second DC power bus 304. Configurations of the fuel cell IT grid system 300 including multiple DC power busses 304 and multiple DC/DC converter 302 electrically connected to associated power modules 12 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical components and connections. Each DC/DC converter 302 may be electrically connected between a power module 12 and a DC power bus 304. The fuel cell IT grid system 300 may include a control device 301 configured to control connections to the load balancing load 306 to implement methods of various embodiments.

[0059] The fuel cell IT grid system 300 may include Q number of IT loads 310. The IT loads 310 may be electrically connected in parallel to the DC power busses 304. In various embodiments, the electrical connection between an IT load 310 and the DC power busses 304 may be dual corded, which may increase reliability of electrical power supply from the DC power busses 304 to the IT load 310 by providing redundant electrical connections. In

various embodiments, an IT load 310 may be electrically connected to the first DC power bus 304 and the second DC power bus 304. The fuel cell IT grid system 300 may include P number of DC/AC inverters 308. Each IT load 310 may be electrically connected to a DC/AC inverter 308. In various embodiments, the dual corded electrical connection between an IT load 310 and the DC power busses 304 may be dual corded between an IT load 310 and an associated DC/AC inverter 308, which may increase reliability of electrical power supply from the power modules 12 to the IT load 310 by providing redundant electrical connections. The fuel cell IT grid system 300 may include a one-to-one ratio of IT loads 310 to DC/AC inverters 308. The DC/AC inverters 308 may be electrically connected in parallel to the DC power busses 304. In various embodiments, a DC/AC inverter 308 electrically connected to a power module 12 may be electrically connected to the first DC power bus 304 and the second DC power bus 304. Each DC/AC inverter 308 may be electrically connected between an IT load 310 and the DC power busses 304.

[0060] The fuel cell IT grid system 300 may be electrically connected to any number or combination of load balancing loads 306. The fuel cell IT grid system 300 may be electrically connected to a load balancing load 306 via at least one of the DC power busses 304. In various embodiments, the fuel cell IT grid system 300 may be electrically connected to a load balancing load 306 via multiple DC power busses 304. In various embodiments, the fuel cell IT grid system 300 may be electrically connected to multiple load balancing loads 306 by electrically connecting each load balancing load 306 to a DC power bus 304. The load balancing load 306 may receive excess electrical power in the fuel cell IT grid system 300, generated by a combination of the power modules 12, beyond the electrical power demand of the IT loads 310.

[0061] FIG. 3C illustrates an example of a fuel cell IT grid system 300 electrically connected to varying numbers and combinations of load balancing loads 306. The fuel cell IT grid system 300 may include N number of power modules 12. The power modules 12 may be electrically connected in parallel to multiple DC power busses 304. The fuel cell IT grid system 300 may include M number of DC/DC converters 302. Each power module 12 may be electrically connected to multiple DC/DC converters 302. The fuel cell IT grid system 300 may include a one-to-many ratio of power modules 12 to DC/DC converters 302. The DC/DC converters 302 may be electrically connected in parallel to the DC power busses 304. In various embodiments, a first DC/DC converter 302 electrically connected to a power

module 12 may be electrically connected to a first DC power bus 304, and a second DC/DC converter 302 electrically connected to the power module 12 may be electrically connected to a second DC power bus 304. Configurations of the fuel cell IT grid system 300 including multiple DC power busses 304 and multiple DC/DC converter 302 electrically connected to associated power modules 12 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical components and connections. Each DC/DC converter 302 may be electrically connected between a power module 12 and a DC power bus 304.

[0062] The fuel cell IT grid system 300 may include Q number of IT loads 310. The IT loads 310 may be electrically connected in parallel to the DC power busses 304. In various embodiments, the electrical connection between an IT load 310 and the DC power busses 304 may be dual corded, which may increase reliability of electrical power supply from the DC power busses 304 to the IT load 310 by providing redundant electrical connections. In various embodiments, an IT load 310 may be electrically connected to the first DC power bus 304 and the second DC power bus 304. The fuel cell IT grid system 300 may include P number of DC/AC inverters 308. Each IT load 310 may be electrically connected to multiple DC/AC inverters 308. The fuel cell IT grid system 300 may include a one-to-many ratio of IT loads 310 to DC/AC inverters 308. The DC/AC inverters 308 may be electrically connected in parallel to the DC power busses 304. In various embodiments, a first DC/AC inverter 308 electrically connected to an IT load 310 may be electrically connected to the first DC power bus 304, and a second DC/AC inverter 308 electrically connected to the IT load 310 may be electrically connected to the second DC power bus 304. Configurations of the fuel cell IT grid system 300 including multiple DC power busses 304 and multiple DC/AC inverters 308 electrically connected to associated IT loads 310 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical components and connections. Each DC/AC inverter 308 may be electrically connected between an IT load 310 and a DC power bus 304.

[0063] The fuel cell IT grid system 300 may be electrically connected to any number or combination of load balancing loads 306. The fuel cell IT grid system 300 may be electrically connected to a load balancing load 306 via at least one of the DC power busses 304. In various embodiments, the fuel cell IT grid system 300 may be electrically connected to a load balancing load 306 via multiple DC power busses 304. In various embodiments, the

fuel cell IT grid system 300 may be electrically connected to multiple load balancing loads 306 by electrically connecting each load balancing load 306 to a DC power bus 304. The load balancing load 306 may receive excess electrical power in the fuel cell IT grid system 300, generated by a combination of the power modules 12, beyond the electrical power demand of the IT loads 310.

[0064] FIG. 3D illustrates an example of a fuel cell IT grid system 300 electrically connected to varying numbers and combinations of load balancing loads 306. The fuel cell IT grid system 300 may include N number of power modules 12. The power modules 12 may be electrically connected in parallel to a DC power bus 304. The fuel cell IT grid system 300 may include M number of DC/DC converters 302. Each power module 12 may be electrically connected to a DC/DC converter 302. The fuel cell IT grid system 300 may include a one-to-one ratio of power modules 12 to DC/DC converters 302. The DC/DC converters 302 may be electrically connected in parallel to the DC power bus 304. Each DC/DC converter 302 may be electrically connected between a power module 12 and the DC power bus 304. The fuel cell IT grid system 300 may include a control device 301 configured to control connections to the load balancing load 306 to implement methods of various embodiments.

[0065] The fuel cell IT grid system 300 may include Q number of IT loads 310. The IT loads 310 may be electrically connected in parallel to the DC power bus 304. In various embodiments, the electrical connection between an IT load 310 and the DC power bus 304 may be dual corded, which may increase reliability of electrical power supply from the DC power bus 304 to the IT load 310 by providing redundant electrical connections. The fuel cell IT grid system 300 may include P number of DC/AC inverters 308. Each IT load 310 may be electrically connected to multiple DC/AC inverters 308. The fuel cell IT grid system 300 may include a one-to-many ratio of IT loads 310 to DC/AC inverters 308. The DC/AC inverters 308 may be electrically connected in parallel to the DC power bus 304. In various embodiments, a first DC/AC inverter 308 electrically connected to an IT load 310 may be electrically connected to the DC power bus 304, and a second DC/AC inverter 308 electrically connected to the IT load 310 may be electrically connected to the DC power bus 304. Configurations of the fuel cell IT grid system 300 including multiple DC/AC inverters 308 electrically connected to associated IT loads 310 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant

electrical components and connections. Each DC/AC inverter 308 may be electrically connected between an IT load 310 and a DC power bus 304.

[0066] The fuel cell IT grid system 300 may be electrically connected to any number or combination of load balancing loads 306. The fuel cell IT grid system 300 may be electrically connected to a load balancing load 306 via the DC power bus 304. The load balancing load 306 may receive excess electrical power in the fuel cell IT grid system 300, generated by a combination of the power modules 12, beyond the electrical power demand of the IT loads 310.

[0067] FIG. 3E illustrates an example of multiple fuel cell IT grid systems 300 electrically connected to varying numbers and combinations of load balancing loads 306. Any number “R” fuel cell IT grid systems 300 may be electrically connected to any number or combination of load balancing loads 306. The fuel cell IT grid systems 300 may be electrically connected to a load balancing load 306 via a DC power bus 304. The load balancing load 306 may receive excess electrical power in the fuel cell IT grid system 300, generated by a combination of the power modules 12, beyond the electrical power demand of the IT loads 310. In various embodiments, the fuel cell IT grid systems 300 may include any combination of configurations of fuel cell IT grid systems 300, such as the configurations of the fuel cell IT grid systems 300 described herein.

[0068] As illustrated in FIGS. 4-10, a fuel cell IT grid system 300 may include any number and combination of a power storage device 402 and an electrical protection component configured to interrupt the flow of electrical current in the fuel cell IT grid system 300. In various embodiments, a fuel cell IT grid system 300 may include a transformer 406. FIGS. 4-10 illustrate various embodiments that are meant to be illustrative examples and not limiting of the scope of the claims.

[0069] Referring to FIGS. 4-10 collectively, a power storage device 402 may include any number and combination of power storage devices 402. For example, a power storage device 402 may include any form of power storage including electromagnetic power storage, mechanical power storage, electrochemical power storage, chemical power storage, and/or thermal power storage. Some non-limiting examples include a capacitor, a flywheel, and/or a battery. A power storage device 402 may increase reliability of electrical power supply to an IT load 310 by providing redundant electrical power supply. In case of insufficient, reduced,

or no electrical output from a power module 12, a power storage device 402 may be used to augment or continue supply of an electrical power demand of an IT load 310. A power storage device 402 may be configured to store electrical power generated by a power module 12. A power storage device 402 may be configured to supply stored electrical power in response to generation of electrical power in a fuel cell IT grid system 300 below an electrical power demand of IT loads 310 of the fuel cell IT grid system 300. A power storage device 402 may receive electrical power from an electrical power source and output the stored electrical power to a DC power bus 304. A fuel cell IT grid system 300 may include any number “S” of DC/DC converters 302, each disposed between a power module 12 and a DC power bus 304. In various embodiments, the electrical power source may include a power module 12, a power storage device 402, and/or an electrical utility grid 802. The fuel cell IT grid system 300 may include a control device 301 configured to control connections to the power storage device 402 and/or a load balancing load 306 to implement methods of various embodiments.

[0070] An electrical protection component may include a fuse, a circuit breaker, and/or a switch. In various embodiments, an electrical protection component may include a DC disconnect 400. A DC disconnect 400 may be configured to connect and disconnect any number and combination of components of a fuel cell IT grid system 300 from a DC power bus 304. A DC disconnect 400 may be configured with a threshold electrical power tolerance. A DC disconnect 400 may be normally configured to connect any number and combination of components of a fuel cell IT grid system 300 to a DC power bus 304. Electrical power supplied to a DC disconnect 400 exceeding its threshold electrical power tolerance may trigger disconnection of any number and combination of components of a fuel cell IT grid system 300 from a DC power bus 304 by the DC disconnect 400. In various embodiments, a DC disconnect 400 may selectively connect and disconnect any number and combination of components of a fuel cell IT grid system 300 from the DC power bus 304. In various embodiments, components of a fuel cell IT grid system 300 may include a power module 12, a power storage device 402, and/or a DC/DC converter 302. In various embodiments, components of a fuel cell IT grid system 300 may include a DC/AC inverter 308, a circuit breaker 404, a transformer 406, and/or an IT load 310 configured to operate using AC electrical current. In various embodiments of the fuel cell IT grid system 300, the IT load 310 may be configured to operate using DC electrical current, and the DC/AC inverter 308 may be omitted from the fuel cell IT grid system 300.

[0071] In various embodiments, an electrical protection component may include a circuit breaker 404. A circuit breaker 404 may be configured to connect and disconnect any number and combination of components of a fuel cell IT grid system 300 from the fuel cell IT grid system 300. A circuit breaker 404 may be configured with a threshold electrical power tolerance. A circuit breaker 404 may be normally configured to connect any number and combination of components of a fuel cell IT grid system 300 to the fuel cell IT grid system 300. Electrical power supplied to a circuit breaker 404 exceeding its threshold electrical power tolerance may trigger disconnection of any number and combination of components of a fuel cell IT grid system 300 from the fuel cell IT grid system 300 by the circuit breaker 404. In various embodiments, components of a fuel cell IT grid system 300 may include a transformer 406 and/or an IT load 310.

[0072] A transformer 406 may be configured to increase or decrease a voltage of an electrical power received from an electrical power source. A transformer 406 may be configured to receive electrical power at an input end and to supply electrical power at an output end. In various embodiments, the electrical power source may include any number and combination of a power module 12, a power storage device 402, and/or an electrical utility grid 802. A transformer 406 may be electrically connected at an input end to an electrical power source and electrically connected to an IT load 310 at an output end. A transformer 406 may be electrically connected to an electrical power source via other components of a fuel cell IT grid system 300 may, such as a DC/AC inverter 308, a DC power bus 304, and/or a DC/DC converter 302. A DC electrical current received by a transformer 406 from an electrical power source via a DC power bus 304 may have its voltage increased or decreased by the transformer 406 and supplied to an IT load 310. An AC electrical current received by a transformer 406 from an electrical power source via a DC/AC inverter 308 may have its voltage increased or decreased by the transformer 406 and supplied to an IT load 310. In various embodiments, a transformer 406 may be configured to supply a designated voltage electrical power based on electrical power configuration of an IT load 310 and/or an electrical power demand of the IT load 310. A fuel cell IT grid system 300 may include P number of transformers 406, each disposed between a DC power bus 304 and an IT load 310. In various embodiments, each transformer 406 may be more specifically disposed between a DC/AC inverter 308 and an IT load 310. In various embodiments, a fuel cell IT grid system 300 may include a one-to-one ratio of transformers 406 to IT loads 310. In various embodiments, a fuel cell IT grid system 300 may include a one-to-many ratio of transformers 406 to IT loads

310. In various embodiments, a transformer 406 may be optional. A transformer 406 may be included on a fuel cell IT grid system 300 for mismatches in the native voltages of the power modules 12 and the IT loads 310, and may be excluded for power modules 12 and the IT loads 310 with matching native voltages.

[0073] FIG. 4 illustrates an example of a fuel cell IT grid system 300 electrically connected to varying numbers and combinations of load balancing loads 306. The fuel cell IT grid system 300 may include N number of power modules 12. The power modules 12 may be electrically connected in parallel to a DC power bus 304. The fuel cell IT grid system 300 may include M number of DC/DC converters 302. Each power module 12 may be electrically connected to a DC/DC converter 302. The fuel cell IT grid system 300 may include a one-to-one ratio of power modules 12 to DC/DC converters 302. The DC/DC converters 302 may be electrically connected in parallel to the DC power bus 304. Each DC/DC converter 302 may be electrically connected between a power module 12 and the DC power bus 304.

[0074] The fuel cell IT grid system 300 may include S number of power storage devices 402. Each power storage device 402 may be electrically connected to a power module 12. A power storage device 402 may be electrically connected to a power module 12 via a DC/DC converter 302. The power storage devices 402 may be electrically connected to the DC power bus 304 in parallel.

[0075] The fuel cell IT grid system 300 may include any number of T electrical protection components configured to electrically connect and disconnect the DC power bus 304 from the power modules 12 and/or the power storage devices 402. In various embodiments, the electrical protection components may include DC disconnects 400. Each DC disconnect 400 may be configured to connect and disconnect a power module 12 and/or a power storage device 402 from the DC power bus 304. In various embodiments, the DC disconnect 400 may selectively connect and disconnect one or both of the power module 12 and the power storage device 402. In various embodiments, the DC disconnect 400 may similarly and additionally connect and disconnect a DC/DC converter 302 from the DC power bus 304.

[0076] The fuel cell IT grid system 300 may include Q number of IT loads 310. The IT loads 310 may be electrically connected in parallel to the DC power bus 304. In various embodiments, the electrical connection between an IT load 310 and the DC power bus 304

may be dual corded, which may increase reliability of electrical power supply from the DC power bus 304 to the IT load 310 by providing redundant electrical connections. The fuel cell IT grid system 300 may include P number of DC/AC inverters 308. Each IT load 310 may be electrically connected to multiple DC/AC inverters 308. The fuel cell IT grid system 300 may include a one-to-many ratio of IT loads 310 to DC/AC inverters 308. The DC/AC inverters 308 may be electrically connected in parallel to the DC power bus 304. In various embodiments, a first DC/AC inverter 308 electrically connected to an IT load 310 may be electrically connected to the DC power bus 304, and a second DC/AC inverter 308 electrically connected to the IT load 310 may be electrically connected to the DC power bus 304. Configurations of the fuel cell IT grid system 300 including multiple DC/AC inverters 308 electrically connected to associated IT loads 310 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical components and connections. Each DC/AC inverter 308 may be electrically connected between an IT load 310 and a DC power bus 304.

[0077] The fuel cell IT grid system 300 may include P number of transformers 406. Each IT load 310 may be electrically connected to multiple transformers 406. The fuel cell IT grid system 300 may include a one-to-many ratio of IT loads 310 to transformers 406. The transformers 406 may be electrically connected in parallel to the DC power bus 304. In various embodiments, a first transformer 406 electrically connected to an IT load 310 may be electrically connected to the DC power bus 304, and a second transformer 406 electrically connected to the IT load 310 may be electrically connected to the DC power bus 304. Each transformer 406 may be electrically connected to the DC power bus 304 via a DC/AC inverter 308. Configurations of the fuel cell IT grid system 300 including multiple transformers 406 electrically connected to associated IT loads 310 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical components and connections. Each transformer 406 may be electrically connected between an IT load 310 and a DC power bus 304. In various embodiments, a fuel cell IT grid system 300 may include a one-to-many ratio of transformers 406 to IT loads 310. In various embodiments, a transformer 406 may be optional. A transformer 406 may be included on a fuel cell IT grid system 300 for mismatches in the native voltages of the power modules 12 and the IT loads 310, and may be excluded for power modules 12 and the IT loads 310 with matching native voltages.

[0078] The fuel cell IT grid system 300 may include P number of electrical protection components configured to electrically connect and disconnect the DC power bus 304 from IT loads 310. In various embodiments, the electrical protection components may include DC disconnects 400. Each DC disconnect 400 may be configured to connect and disconnect an IT load 310 from the DC power bus 304. In various embodiments, the DC disconnect 400 may similarly and additionally connect and disconnect a DC/AC inverter 308, a circuit breaker 404, and/or a transformer 406 from the DC power bus 304. In various embodiments, the DC disconnect 400 may connect and disconnect one of multiple inputs of the IT load 310 from the DC power bus 304.

[0079] The fuel cell IT grid system 300 may include P number of electrical protection components configured to electrically connect and disconnect components of a fuel cell IT grid system 300 from the fuel cell IT grid system 300. In various embodiments, the electrical protection components may include circuit breakers 404. In various embodiments, components of a fuel cell IT grid system 300 may include a transformer 406 and/or an IT load 310. Each circuit breaker 404 may be configured to connect and disconnect an IT load 310 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may similarly and additionally connect and disconnect a transformer 406 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may connect and disconnect one of multiple inputs of the IT load 310 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may be electrically connected between an IT load 310 and a DC/AC inverter 308. In various embodiments, the circuit breaker 404 may be electrically connected between a transformer 404 electrically connected to an IT load 310 and a DC/AC inverter 308.

[0080] The fuel cell IT grid system 300 may be electrically connected to any number or combination of load balancing loads 306. The fuel cell IT grid system 300 may be electrically connected to a load balancing load 306 via the DC power bus 304. The load balancing load 306 may receive excess electrical power in the fuel cell IT grid system 300, generated by a combination of the power modules 12, beyond the electrical power demand of the IT loads 310. In various embodiments, the load balancing load 306 may be electrically connected to and disconnected from the fuel cell IT grid system 300 by electrical protection components. In various embodiments, an electrical protection component may include a DC disconnect 400.

[0081] The fuel cell IT grid system 300 may include a control device 301 configured to receive signals from and control connections to the various components of the system to implement methods of various embodiments.

[0082] FIG. 5 illustrates an example of a fuel cell IT grid system 300 electrically connected to varying numbers and combinations of load balancing loads 306. The fuel cell IT grid system 300 may include N number of power modules 12. The power modules 12 may be electrically connected in parallel to multiple DC power busses 304. The fuel cell IT grid system 300 may include M number of DC/DC converters 302. Each power module 12 may be electrically connected to a DC/DC converter 302. The fuel cell IT grid system 300 may include a one-to-one ratio of power modules 12 to DC/DC converters 302. The DC/DC converters 302 may be electrically connected in parallel to the DC power busses 304. Configurations of the fuel cell IT grid system 300 including multiple DC power busses 304 electrically connected to the power modules 12 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical connections. Each DC/DC converter 302 may be electrically connected between a power module 12 and the DC power busses 304.

[0083] The fuel cell IT grid system 300 may include S number of power storage devices 402. Each power storage device 402 may be electrically connected to a power module 12. A power storage device 402 may be electrically connected to a power module 12 via a DC/DC converter 302. The fuel cell IT grid system 300 may include a one-to-many ratio of power modules 12 to power storage devices 402. The power storage devices 402 may be electrically connected to the DC power busses 304 in parallel. In various embodiments, a first power storage device 402 may be electrically connected between a DC/DC converter 302 and a first DC power bus 304, and a second power storage device 402 may be electrically connected between the DC/DC converter 302 and a second DC power bus 304. Configurations of the fuel cell IT grid system 300 including multiple power storage devices 402 electrically connected to associated power modules 12 may increase reliability of electrical power supply from the power storage devices 402 to the IT loads 310 by providing redundant electrical components and connections.

[0084] The fuel cell IT grid system 300 may include any number of T of electrical protection components configured to electrically connect and disconnect the DC power busses 304 from the power modules 12 and/or the power storage devices 402. In various embodiments, the

electrical protection components may include DC disconnects 400. Each DC disconnect 400 may be configured to connect and disconnect a power module 12 and/or a power storage device 402 from a DC power bus 304. In various embodiments, the DC disconnect 400 may selectively connect and disconnect one of or both the power module 12 and the power storage device 402 electrically connected to the DC disconnect 400. In various embodiments, a first DC disconnect 400 may electrically connect and disconnect a power module 12 and a first power storage device 402 from the first DC power bus 304, and a second DC disconnect 400 may electrically connect and disconnect the power module 12 and a second power storage device 402 from the second DC power bus 304. In various embodiments, a DC disconnect 400 may similarly and additionally connect and disconnect a DC/DC converter 302 from a DC power bus 304.

[0085] The fuel cell IT grid system 300 may include Q number of IT loads 310. The IT loads 310 may be electrically connected in parallel to the DC power busses 304. In various embodiments, the electrical connection between an IT load 310 and the DC power busses 304 may be dual corded, which may increase reliability of electrical power supply from the DC power busses 304 to the IT load 310 by providing redundant electrical connections. In various embodiments, an IT load 310 may be electrically connected to the first DC power bus 304 and the second DC power bus 304. The fuel cell IT grid system 300 may include P number of DC/AC inverters 308. Each IT load 310 may be electrically connected to multiple DC/AC inverters 308. The fuel cell IT grid system 300 may include a one-to-many ratio of IT loads 310 to DC/AC inverters 308. The DC/AC inverters 308 may be electrically connected in parallel to the DC power busses 304. In various embodiments, a first DC/AC inverter 308 electrically connected to an IT load 310 may be electrically connected to the first DC power bus 304, and a second DC/AC inverter 308 electrically connected to the IT load 310 may be electrically connected to the second DC power bus 304. Configurations of the fuel cell IT grid system 300 including multiple DC power busses 304 and multiple DC/AC inverters 308 electrically connected to associated IT loads 310 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical components and connections. Each DC/AC inverter 308 may be electrically connected between an IT load 310 and a DC power bus 304, electrically connecting the IT load 310 to the DC power bus 304.

[0086] The fuel cell IT grid system 300 may include P number of transformers 406. Each IT load 310 may be electrically connected to multiple transformers 406. The fuel cell IT grid system 300 may include a one-to-many ratio of IT loads 310 to transformers 406. The transformers 406 may be electrically connected in parallel to the DC power busses 304. In various embodiments, a first transformer 406 electrically connected to an IT load 310 may be electrically connected to the first DC power bus 304, and a second transformer 406 electrically connected to the IT load 310 may be electrically connected to the second DC power bus 304. Each transformer 406 may be electrically connected to the DC power busses 304 via a DC/AC inverter 308. Configurations of the fuel cell IT grid system 300 including multiple transformers 406 electrically connected to associated IT loads 310 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical components and connections. Each transformer 406 may be electrically connected between an IT load 310 and a DC power bus 304, electrically connecting the IT load 310 to the DC power bus 304. In various embodiments, a fuel cell IT grid system 300 may include a one-to-many ratio of transformers 406 to IT loads 310. In various embodiments, a transformer 406 may be optional. A transformer 406 may be included on a fuel cell IT grid system 300 for mismatches in the native voltages of the power modules 12 and the IT loads 310, and may be excluded for power modules 12 and the IT loads 310 with matching native voltages.

[0087] The fuel cell IT grid system 300 may include P number of electrical protection components configured to electrically connect and disconnect the DC power busses 304 from IT loads 310. In various embodiments, the electrical protection components may include DC disconnects 400. Each DC disconnect 400 may be configured to connect and disconnect an IT load 310 from the DC power busses 304. In various embodiments, a first DC disconnect 400 may be configured to connect and disconnect an IT load 310 from the first DC power bus 304, and a second DC disconnect 400 may be configured to connect and disconnect the IT load 310 from the second DC power bus. In various embodiments, the DC disconnect 400 may similarly and additionally connect and disconnect a DC/AC inverter 308, a circuit breaker 404, and/or a transformer 406 from a DC power bus 304.

[0088] The fuel cell IT grid system 300 may include P number of electrical protection components configured to electrically connect and disconnect components of a fuel cell IT grid system 300 from the fuel cell IT grid system 300. In various embodiments, the electrical

protection components may include circuit breakers 404. In various embodiments, components of a fuel cell IT grid system 300 may include a transformer 406 and/or an IT load 310. Each circuit breaker 404 may be configured to connect and disconnect an IT load 310 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may similarly and additionally connect and disconnect a transformer 406 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may connect and disconnect one of multiple inputs of the IT load 310 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may be electrically connected between an IT load 310 and a DC/AC inverter 308. In various embodiments, the circuit breaker 404 may be electrically connected between a transformer 404 electrically connected to an IT load 310 and a DC/AC inverter 308.

[0089] The fuel cell IT grid system 300 may be electrically connected to any number V or combination of load balancing loads 306. The fuel cell IT grid system 300 may be electrically connected to the load balancing loads 306 via the DC power busses 304. The load balancing loads 306 may receive excess electrical power in the fuel cell IT grid system 300, generated by a combination of the power modules 12, beyond the electrical power demand of the IT loads 310. In various embodiments, the fuel cell IT grid system 300 may be electrically connected to a first load balancing load 306 via the first DC power bus 304, and the fuel cell IT grid system 300 may be electrically connected to a second load balancing load 306 via the second DC power bus 304. In various embodiments, the load balancing loads 306 may be electrically connected to and disconnected from the fuel cell IT grid system 300 by electrical protection components. In various embodiments, the electrical protection components may include DC disconnects 400 configured to electrically connect and disconnect an associated load balancing load 306 from an associated DC power bus 304.

[0090] The fuel cell IT grid system 300 may include a control device 301 configured to receive signals from and control connections to the various components of the system to implement methods of various embodiments.

[0091] FIG. 6 illustrates an example of a fuel cell IT grid system 300 electrically connected to varying numbers and combinations of load balancing loads 306, 600. The fuel cell IT grid system 300 may include N number of power modules 12. The power modules 12 may be electrically connected in parallel to a DC power bus 304. The fuel cell IT grid system 300 may include M number of DC/DC converters 302. Each power module 12 may be

electrically connected to a DC/DC converter 302. The fuel cell IT grid system 300 may include a one-to-one ratio of power modules 12 to DC/DC converters 302. The DC/DC converters 302 may be electrically connected in parallel to the DC power bus 304. Each DC/DC converter 302 may be electrically connected between a power module 12 and the DC power bus 304.

[0092] The fuel cell IT grid system 300 may include S number of power storage devices 402. Each power storage device 402 may be electrically connected to a power module 12. A power storage device 402 may be electrically connected to a power module 12 via a DC/DC converter 302. The power storage devices 402 may be electrically connected to the DC power bus 304 in parallel.

[0093] The fuel cell IT grid system 300 may include any number T of electrical protection components configured to electrically connect and disconnect the DC power bus 304 from the power modules 12 and/or the power storage devices 402. In various embodiments, the electrical protection components may include DC disconnects 400. Each DC disconnect 400 may be configured to connect and disconnect a power module 12 and/or a power storage device 402 from the DC power bus 304. In various embodiments, the DC disconnect 400 may selectively connect and disconnect one of or both the power module 12 and the power storage device 402 electrically connected to the DC disconnect 400. In various embodiments, the DC disconnect 400 may similarly and additionally connect and disconnect a DC/DC converter 302 from the DC power bus 304.

[0094] The fuel cell IT grid system 300 may include Q number of IT loads 310. The IT loads 310 may be electrically connected in parallel to the DC power bus 304. In various embodiments, the electrical connection between an IT load 310 and the DC power bus 304 may be dual corded, which may increase reliability of electrical power supply from the DC power bus 304 to the IT load 310 by providing redundant electrical connections. The fuel cell IT grid system 300 may include P number of DC/AC inverters 308. Each IT load 310 may be electrically connected to multiple DC/AC inverters 308. The fuel cell IT grid system 300 may include a one-to-many ratio of IT loads 310 to DC/AC inverters 308. The DC/AC inverters 308 may be electrically connected in parallel to the DC power bus 304. In various embodiments, a first DC/AC inverter 308 electrically connected to an IT load 310 may be electrically connected to the DC power bus 304, and a second DC/AC inverter 308 electrically connected to the IT load 310 may be electrically connected to the DC power bus

304. Configurations of the fuel cell IT grid system 300 including multiple DC/AC inverters 308 electrically connected to associated IT loads 310 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical components and connections. Each DC/AC inverter 308 may be electrically connected between an IT load 310 and a DC power bus 304, electrically connecting the IT load 310 to the DC power bus 304.

[0095] The fuel cell IT grid system 300 may include P number of transformers 406. Each IT load 310 may be electrically connected to multiple transformers 406. The fuel cell IT grid system 300 may include a one-to-many ratio of IT loads 310 to transformers 406. The transformers 406 may be electrically connected in parallel to the DC power bus 304. In various embodiments, a first transformer 406 electrically connected to an IT load 310 may be electrically connected to the DC power bus 304, and a second transformer 406 electrically connected to the IT load 310 may be electrically connected to the DC power bus 304. Each transformer 406 may be electrically connected to the DC power bus 304 via a DC/AC inverter 308. Configurations of the fuel cell IT grid system 300 including multiple transformers 406 electrically connected to associated IT loads 310 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical components and connections. Each transformer 406 may be electrically connected between an IT load 310 and a DC power bus 304, electrically connecting the IT load 310 to the DC power bus 304. In various embodiments, a fuel cell IT grid system 300 may include a one-to-many ratio of transformers 406 to IT loads 310. In various embodiments, a transformer 406 may be optional. A transformer 406 may be included on a fuel cell IT grid system 300 for mismatches in the native voltages of the power modules 12 and the IT loads 310, and may be excluded for power modules 12 and the IT loads 310 with matching native voltages.

[0096] The fuel cell IT grid system 300 may include P number of electrical protection components configured to electrically connect and disconnect the DC power bus 304 from IT loads 310. In various embodiments, the electrical protection components may include DC disconnects 400. Each DC disconnect 400 may be configured to connect and disconnect an IT load 310 from the DC power bus 304. In various embodiments, the DC disconnect 400 may similarly and additionally connect and disconnect a DC/AC inverter 308, a circuit breaker 404, and/or a transformer 406 from the DC power bus 304. In various embodiments,

the DC disconnect 400 may connect and disconnect one of multiple inputs of the IT load 310 from the DC power bus 304.

[0097] The fuel cell IT grid system 300 may include P number of electrical protection components configured to electrically connect and disconnect components of a fuel cell IT grid system 300 from the fuel cell IT grid system 300. In various embodiments, the electrical protection components may include circuit breakers 404. In various embodiments, components of a fuel cell IT grid system 300 may include a transformer 406 and/or an IT load 310. Each circuit breaker 404 may be configured to connect and disconnect an IT load 310 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may similarly and additionally connect and disconnect a transformer 406 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may connect and disconnect one of multiple inputs of the IT load 310 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may be electrically connected between an IT load 310 and a DC/AC inverter 308. In various embodiments, the circuit breaker 404 may be electrically connected between a transformer 404 electrically connected to an IT load 310 and a DC/AC inverter 308.

[0098] The fuel cell IT grid system 300 may be electrically connected to any number or combination of load balancing loads 306. In various embodiments, a load balancing load 306 may include a mechanical load 600. The fuel cell IT grid system 300 may be electrically connected to multiple load balancing loads 306 via the DC power bus 304. The load balancing loads 306 may receive excess electrical power in the fuel cell IT grid system 300, generated by a combination of the power modules 12, beyond the electrical power demand of the IT loads 310. In various embodiments, a load balancing load 306 may be electrically connected to and disconnected from the fuel cell IT grid system 300 by electrical protection components. In various embodiments, an electrical protection component may include a DC disconnect 400. In various embodiments, the load balancing load 306 may be any load that requires AC electrical power, such as an AC mechanical load 600. An AC mechanical load 600 may be electrically connected to the DC power bus 304 via a DC/AC inverter 308.

[0099] FIGS. 7 and 8 illustrate examples of a fuel cell IT grid system 300 electrically connected to varying numbers and combinations of load balancing loads 306, 600. The fuel cell IT grid system 300 may include N number of power modules 12. The power modules 12 may be electrically connected in parallel to a DC power bus 304. The fuel cell IT grid system

300 may include M number of DC/DC converters 302. Each power module 12 may be electrically connected to a DC/DC converter 302. The fuel cell IT grid system 300 may include a one-to-one ratio of power modules 12 to DC/DC converters 302. The DC/DC converters 302 may be electrically connected in parallel to the DC power bus 304. Each DC/DC converter 302 may be electrically connected between a power module 12 and the DC power bus 304.

[0100] The fuel cell IT grid system 300 may include S number of power storage devices 402. Each power storage device 402 may be electrically connected to a power module 12. A power storage device 402 may be electrically connected to a power module 12 via a DC/DC converter 302. The power storage devices 402 may be electrically connected to the DC power bus 304 in parallel. The fuel cell IT grid system 300 may include any number T of electrical protection components configured to electrically connect and disconnect the DC power bus 304 from the power modules 12 and/or the power storage devices 402. In various embodiments, the electrical protection components may include DC disconnects 400. Each DC disconnect 400 may be configured to connect and disconnect a power module 12 and/or a power storage device 402 from the DC power bus 304. In various embodiments, the DC disconnect 400 may selectively connect and disconnect one of or both the power module 12 and the power storage device 402 electrically connected to the DC disconnect 400. In various embodiments, the DC disconnect 400 may similarly and additionally connect and disconnect a DC/DC converter 302 from the DC power bus 304.

[0101] The fuel cell IT grid system 300 may include Q number of IT loads 310. The IT loads 310 may be electrically connected in parallel to the DC power bus 304. In various embodiments, the electrical connection between an IT load 310 and the DC power bus 304 may be dual corded, which may increase reliability of electrical power supply from the DC power bus 304 to the IT load 310 by providing redundant electrical connections. The fuel cell IT grid system 300 may include P number of DC/AC inverters 308. Each IT load 310 may be electrically connected to multiple DC/AC inverters 308. The fuel cell IT grid system 300 may include a one-to-many ratio of IT loads 310 to DC/AC inverters 308. The DC/AC inverters 308 may be electrically connected in parallel to the DC power bus 304. In various embodiments, a first DC/AC inverter 308 electrically connected to an IT load 310 may be electrically connected to the DC power bus 304, and a second DC/AC inverter 308 electrically connected to the IT load 310 may be electrically connected to the DC power bus

304. Configurations of the fuel cell IT grid system 300 including multiple DC/AC inverters 308 electrically connected to associated IT loads 310 may increase reliability of electrical power supply from the power modules 12 to the IT loads 310 by providing redundant electrical components and connections. Each DC/AC inverter 308 may be electrically connected between an IT load 310 and a DC power bus 304, electrically connecting the IT load 310 to the DC power bus 304.

[0102] The fuel cell IT grid system 300 may include P number of electrical protection components configured to electrically connect and disconnect the DC power bus 304 from IT loads 310. In various embodiments, the electrical protection components may include DC disconnects 400. Each DC disconnect 400 may be configured to connect and disconnect an IT load 310 from the DC power bus 304. In various embodiments, the DC disconnect 400 may similarly and additionally connect and disconnect a DC/AC inverter 308 from the DC power bus 304. In various embodiments, the DC disconnect 400 may connect and disconnect one of multiple inputs of the IT load 310 from the DC power bus 304.

[0103] In various embodiments, the fuel cell IT grid system 300 may further include any number and combination of additional power modules 12, DC/DC converters 302, and electrical protection components in other configurations. In various embodiments, electrical protection components may include DC disconnects 400. An additional power module 12 may be electrically connected to the DC power bus in parallel with the N number of power modules 12. The additional power module 12 may be configured like the N number of power modules 12. However, the additional power module 12 may be redundant to the N number of power modules 12, and configured to provide electrical power to the IT loads 310 in response to the N number of power modules 12 providing insufficient electrical power to satisfy an electrical power demand of the IT loads 310. In various aspects, the additional power module 12 may normally provide electrical power to the DC power bus 304 in excess of the electrical power demands of the IT loads 310. The additional power module 12 may normally operate to maintain a temperature above its temperature threshold. An additional DC/DC converter may be configured similar to the M number of DC/DC converters 302, and electrically connect the additional power module 12 to the DC power bus. An additional DC disconnect 400 may be configured similar to the M number of DC disconnects 400, to electrically connect and disconnect the additional power module 12 and/or the additional DC/DC converter 302 from the DC power bus. In various embodiments, an additional DC disconnect

400 may be configured to connect and disconnect the DC power bus 304 from any number and combination of load balancing loads 306, 600.

[0104] The fuel cell IT grid system 300 may include a control device 301 configured to receive signals from and control connections to the various components of the system to implement methods of various embodiments.

[0105] The example illustrated in FIG. 7 demonstrates that the fuel cell IT grid system 300 may be electrically connected to any number or combination of load balancing loads 306. In various embodiments, a load balancing load 306 may include a mechanical load 600. The fuel cell IT grid system 300 may be electrically connected to multiple load balancing loads 306 via the DC power bus 304. The load balancing loads 306 may receive excess electrical power in the fuel cell IT grid system 300, generated by a combination of the power modules 12, beyond the electrical power demand of the IT loads 310. In various embodiments, a DC/DC converter 302 may be electrically connected to a DC load balancing load 306 and configured to convert a DC electrical power received from the fuel cell IT grid system 300 to a DC electrical current consumable by the load balancing load 306. In various embodiments, the load balancing load 306 may be electrically connected to and disconnected from the fuel cell IT grid system 300 by electrical protection components. In various embodiments, an electrical protection component may include a DC disconnect 400. The DC disconnect 400 may be configured to connect and disconnect the load balancing load 306 and/or the DC/DC converter 302 from the DC power bus 304 of the fuel cell IT grid system 300.

[0106] In various embodiments, the load balancing load 306 may be any load that requires AC electrical power, such as an AC mechanical load 600. An AC mechanical load 600 may be electrically connected to the DC power bus 304 via a DC/AC inverter 308. The DC/AC inverter 308 may be configured to invert the DC electrical power received from the fuel cell IT grid system 300 to an AC electrical power consumable by the mechanical load 600. In various embodiments, the mechanical load 600 may be electrically connected to R number of fuel cell IT grid systems 300. Each connected fuel cell IT grid system 300 may be electrically connected to the mechanical load 600 via a DC/AC inverter 308.

[0107] The fuel cell IT grid system 300 may include a control device 301 configured to receive signals from and control connections to the various components of the system to implement methods of various embodiments.

[0108] The example illustrated in FIG. 8 demonstrates that the fuel cell IT grid system 300 may be electrically connected to any number or combination of load balancing loads. In various embodiments, a load balancing load may include a mechanical load 600. In various embodiments, a load balancing load may include an electrical utility grid 802. The fuel cell IT grid system 300 may be electrically connected to multiple load balancing loads via the DC power bus 304. The load balancing loads may receive excess electrical power generated by a combination of the power modules 12 in the fuel cell IT grid system 300 beyond the electrical power demand of the IT loads 310. In various embodiments, the load balancing load may be any load that requires AC electrical power. A load balancing load may be electrically connected to the DC power bus 304 via a DC/AC inverter 308 or a bidirectional DC/AC inverter 800. The DC/AC inverter 308 or the bidirectional DC/AC inverter 800 may be configured to invert the DC electrical power received from the fuel cell IT grid system 300 to an AC electrical power consumable by the load balancing load. In various embodiments, the mechanical load 600 may be electrically connected to R number of fuel cell IT grid systems 300. Each connected fuel cell IT grid system 300 may be electrically connected to the mechanical load 600 via a DC/AC inverter 308.

[0109] The electrical utility grid 802 may also provide electrical power to the fuel cell IT grid system 300 in response to electrical power in the fuel cell IT grid system 300 being insufficient to meet the electrical power demands of the IT loads 310 of the fuel cell IT grid system 300. The bidirectional DC/AC inverter may be configured to invert AC electrical power provided by the electrical utility grid 802 to a DC electrical power and provide the DC electrical power to the DC power bus 304 of the fuel cell IT grid system 300. In a fuel cell IT grid system 300, DC electrical power provided to the DC power bus 304 may be directed to the IT loads 310 via a DC/AC inverter 308 to supplement the DC electrical power generated in the fuel cell IT grid system 300 and to meet the electrical power demands of the IT loads.

[0110] FIGS. 9 and 10 illustrate examples of a fuel cell IT grid system 300 electrically connected to varying numbers and combinations of load balancing loads 306, 600. The fuel cell IT grid system 300 may include N number of power modules 12. The power modules 12 may be electrically connected in parallel to a DC power bus 304. The fuel cell IT grid system 300 may include M number of DC/DC converters 302. Each power module 12 may be electrically connected to a DC/DC converter 302. The fuel cell IT grid system 300 may include a one-to-one ratio of power modules 12 to DC/DC converters 302. The DC/DC

converters 302 may be electrically connected in parallel to the DC power bus 304. Each DC/DC converter 302 may be electrically connected between a power module 12 and the DC power bus 304.

[0111] The fuel cell IT grid system 300 may include S number of power storage devices 402. Each power storage device 402 may be electrically connected to a power module 12. A power storage device 402 may be electrically connected to a power module 12 via a DC/DC converter 302. The power storage devices 402 may be electrically connected to the DC power bus 304 in parallel.

[0112] The fuel cell IT grid system 300 may include any number T of electrical protection components configured to electrically connect and disconnect the DC power bus 304 from the power modules 12 and/or the power storage devices 402. In various embodiments, the electrical protection components may include DC disconnects 400. Each DC disconnect 400 may be configured to connect and disconnect a power module 12 and/or a power storage device 402 from the DC power bus 304. In various embodiments, the DC disconnect 400 may selectively connect and disconnect one of or both the power module 12 and the power storage device 402 electrically connected to the DC disconnect 400. In various embodiments, the DC disconnect 400 may similarly and additionally connect and disconnect a DC/DC converter 302 from the DC power bus 304.

[0113] The fuel cell IT grid system 300 may include Q number of IT loads 310. The IT loads 310 may be electrically connected in parallel to the DC power bus 304. In various embodiments, the electrical connection between an IT load 310 and the DC power bus 304 may be dual corded, which may increase reliability of electrical power supply from the DC power bus 304 to the IT load 310 by providing redundant electrical connections. The fuel cell IT grid system 300 may include P number of DC/AC inverters 308. Each IT load 310 may be electrically connected to a DC/AC inverter 308. The fuel cell IT grid system 300 may include a one-to-one ratio of IT loads 310 to DC/AC inverters 308. The DC/AC inverters 308 may be electrically connected in parallel to the DC power bus 304. Each DC/AC inverter 308 may be electrically connected between an IT load 310 and a DC power bus 304, electrically connecting the IT load 310 to the DC power bus 304.

[0114] The fuel cell IT grid system 300 may include P number of electrical protection components configured to electrically connect and disconnect the DC power bus 304 from IT

loads 310. In various embodiments, the electrical protection components may include DC disconnects 400. Each DC disconnect 400 may be configured to connect and disconnect an IT load 310 from the DC power bus 304. In various embodiments, the DC disconnect 400 may similarly and additionally connect and disconnect a DC/AC inverter 308 and/or a circuit breaker 404 from the DC power bus 304.

[0115] The fuel cell IT grid system 300 may include any number “X” of electrical protection components configured to electrically connect and disconnect IT loads 310 from the fuel cell IT grid system 300. In various embodiments, the electrical protection components may include circuit breakers 404. Each circuit breaker 404 may be configured to connect and disconnect an IT load 310 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may connect and disconnect one of multiple inputs of the IT load 310 from the fuel cell IT grid system 300. In various embodiments, the circuit breaker 404 may be electrically connected between an IT load 310 and a DC/AC inverter 308.

[0116] In various embodiments, the fuel cell IT grid system 300 may further include any number and combination of additional power modules 12, DC/DC converters 302, and electrical protection components in other configurations. In various embodiments, electrical protection components may include DC disconnects 400. An additional power module 12 may be electrically connected to the DC power bus in parallel with the N number of power modules 12. The additional power module 12 may be configured like the N number of power modules 12. However, the additional power module 12 may be redundant to the N number of power modules 12, and configured to provide electrical power to the IT loads 310 in response to the N number of power modules 12 providing insufficient electrical power to satisfy an electrical power demand of the IT loads 310. In various aspects, the additional power module 12 may normally provide electrical power to the DC power bus 304 in excess of the electrical power demands of the IT loads 310. The additional power module 12 may normally operate to maintain a temperature above its temperature threshold. An additional DC/DC converter may be configured similar to the M number of DC/DC converter 302, electrically connecting the additional power module 12 to the DC power bus. An additional DC disconnect 400 may be configured similar to the M number of DC disconnects 400, and electrically connect and disconnect the additional power module 12 and/or the additional DC/DC converter 302 from the DC power bus. In various embodiments, an additional DC disconnect 400 may be

configured to connect and disconnect the DC power bus 304 from any number and combination of load balancing loads 306, 600.

[0117] The fuel cell IT grid system 300 may include a control device 301 configured to receive signals from and control connections to the various components of the system to implement methods of various embodiments.

[0118] The example illustrated in FIG. 9 demonstrates that the fuel cell IT grid system 300 may be electrically connected to any number or combination of load balancing loads 306. In various embodiments, a load balancing load 306 may include a DC mechanical load 600. The fuel cell IT grid system 300 may be electrically connected to multiple load balancing loads 306 via the DC power bus 304. The load balancing loads 306 may receive excess electrical power in the fuel cell IT grid system 300, generated by a combination of the power modules 12, beyond the electrical power demand of the IT loads 310. In various embodiments, a DC/DC converter 302 may be electrically connected to a DC load balancing load 306 and configured to convert a DC electrical power received from the fuel cell IT grid system 300 to a DC electrical current consumable by the load balancing load 306. In various embodiments, the load balancing load 306 may be electrically connected to and disconnected from the fuel cell IT grid system 300 by electrical protection components. In various embodiments, an electrical protection component may include a DC disconnect 400. The DC disconnect 400 may be configured to connect and disconnect the load balancing load 306 and/or the DC/DC converter 302 from the DC power bus 304 of the fuel cell IT grid system 300.

[0119] In various embodiments, the load balancing load 306 may be any load that requires AC electrical power, such as an AC mechanical load 600. An AC mechanical load 600 may be electrically connected to the DC power bus 304 via a DC/AC inverter 308. The DC/AC inverter 308 may be configured to invert the DC electrical power received from the fuel cell IT grid system 300 to an AC electrical power consumable by the mechanical load 600. In various embodiments, the mechanical load 600 may be electrically connected to R number of fuel cell IT grid systems 300. Each connected fuel cell IT grid system 300 may be electrically connected to the mechanical load 600 via a DC/AC inverter 308.

[0120] The fuel cell IT grid system 300 may include a control device 301 configured to receive signals from and control connections to the various components of the system to implement methods of various embodiments.

[0121] The example illustrated in FIG. 10 demonstrates that the fuel cell IT grid system 300 may be electrically connected to any number or combination of load balancing loads. In various embodiments, a load balancing load may include a mechanical load 600. In various embodiments, a load balancing load may include an electrical utility grid 802. The fuel cell IT grid system 300 may be electrically connected to multiple load balancing loads via the DC power bus 304. The load balancing loads may receive excess electrical power generated by a combination of the power modules 12 in the fuel cell IT grid system 300 beyond the electrical power demand of the IT loads 310. In various embodiments, the load balancing load may be any load that requires AC electrical power. A load balancing load may be electrically connected to the DC power bus 304 via a DC/AC inverter 308 or a bidirectional DC/AC inverter 800. The DC/AC inverter 308 or the bidirectional DC/AC inverter 800 may be configured to invert the DC electrical power received from the fuel cell IT grid system 300 to an AC electrical power consumable by the AC load balancing load. In various embodiments, the mechanical load 600 may be electrically connected to R number of fuel cell IT grid systems 300. Each connected fuel cell IT grid system 300 may be electrically connected to the mechanical load 600 via a DC/AC inverter 308.

[0122] The electrical utility grid 802 may also provide electrical power to the fuel cell IT grid system 300 in response to electrical power in the fuel cell IT grid system 300 being insufficient to meet the electrical power demands of the IT loads 310 of the fuel cell IT grid system 300. The bidirectional DC/AC inverter may be configured to invert an AC electrical power provided by the electrical utility grid 802 to a DC electrical power and provide the DC electrical power to the DC power bus 304 of the fuel cell IT grid system 300. The DC electrical power provided to the DC power bus 304 may be directed to the IT loads 310, via a DC/AC inverter 308 if the fuel cell IT grid system 300, to supplement the DC electrical power generated in the fuel cell IT grid system 300 and to meet the electrical power demands of the IT loads.

[0123] In various embodiments, the fuel cell IT grid system 300 and/or the components of the fuel cell IT grid system 300, examples of which are illustrated in FIGS. 3-10, may include any number and combination of control devices 301 (e.g., programmable processing devices

configured to execute computer code) configured to control the functions of any number and combination of the components of the fuel cell IT grid system 300. Similarly, any number and combination of control device(s) 301 s may be implemented to control the functions of the load balancing loads 306, including the mechanical load 600 and/or the electrical utility grid 802, and the components electrically connecting the load balancing loads 306 to the fuel cell IT grid system 300. The control device(s) 301 s may be configured to monitor the operation and functions of the fuel cell IT grid system 300, the components of the fuel cell IT grid system 300, the load balancing loads 306, and/or the components electrically connecting the load balancing loads 306 to the fuel cell IT grid system 300. The control device(s) 301 s may be communicatively connected and configured to send signals between the control device(s) 301 s relating to the operation and functions of the fuel cell IT grid system 300, the components of the fuel cell IT grid system 300, the load balancing loads 306, and/or the components electrically connecting the load balancing loads 306 to the fuel cell IT grid system 300. The control device(s) 301 s may be configured to interpret signals received from another control device(s) 301 . In various embodiments, controlling the functions, monitoring the operation and functions, sending signals relating to the operation and functions, and interpreting received signals may relate to maintaining a temperature of a power module 12 above a temperature threshold, determining and responding to an electrical power demand of an IT load 310, and directing excess electrical power from the fuel cell IT grid system 300 to a load balancing load 360, 600, 802.

[0124] The fuel cell IT grid system 300 may include a control device 301 configured to receive signals from and control connections to the various components of the system to implement methods of various embodiments.

[0125] FIG. 11 illustrates a method 1100 for managing a fuel cell IT grid system 300 according to various embodiments. The method 1100 may be implemented using one or more control devices 301 configured to receive signals from and/or send control signals to any number or combination of power modules 12, DC/DC converters 302, DC power busses 304, load balancing loads 306, including mechanical loads 600 and/or electrical grids 802, DC/AC inverters 308, IT loads 310, electrical protection components, including DC disconnects 400 and/or circuit breakers 404, power storage devices 402, transformers 406, and/or bidirectional DC/AC inverters 800. In order to encompass the alternative

configurations enabled in various embodiments, the hardware implementing the method 1100 is referred to herein as a “control device.”

[0126] In block 1101, a control device may receive, from a sensor in the power module 12 and/or a control device of the power module 12, a signal indicative of the temperature and/or the power output of a power module 12.

[0127] In determination block 1102, a control device may determine whether a temperature of the power module 12 exceeds a temperature threshold for the power module 12. As described above, the temperature threshold may be a temperature at which heating the power module 12 to a temperature above the temperature threshold from a temperature below the temperature threshold may fatigue or damage components of the power module 12.

[0128] In some embodiments, the control device may compare a temperature of the power module 12 based upon temperature indication signals obtained in block 1101 to the temperature threshold of the power module 12 in determination block 1102.

[0129] The temperature of the power module 12 may be correlated with an electrical power output of the power module 12. Thus, in some embodiments, electrical output of the power module 12 obtained in block 1101 may be used to determine and control the temperature of the power module. To determine whether the temperature of the power module 12 exceeds the temperature of the power module 12 in determination block 1102, the control device may determine whether the electrical output of the power module 12 exceeds an electrical power output threshold of the power module 12. The control device may compare the electrical output of the power module 12 received in block 1101 to the electrical power output threshold of the power module 12. In some embodiments, the control device may convert the electrical power output of the power module 12 into temperature units, and compare the calculated temperature of the power module 12 to the temperature threshold for the power module 12.

[0130] In response to determining that the temperature of the power module 12 exceeds the temperature threshold for the power module 12 (i.e., determination block 1102 = “Yes”), the control device may maintain the electrical power output of the power module 12 in block 1106. As noted herein, the temperature of the power module 12 may correlate with the electrical power output of the power module 12. Therefore, maintaining the electrical power

output of the power module 12 may serve to maintain the temperature of the power module 12 above the temperature threshold.

[0131] In various embodiments, at any point during execution of the method 1100, the control device may receive an electrical power demand signal in block 1104. In various embodiments, the electrical power demand signal may be or may indicate a change in the electrical power demand of the IT loads 310 in the fuel cell IT grid system 300. In various embodiments, the control device may continuously receive an electrical power demand signal, and may determine when there is a change in the continuously received electrical power demand signal. In block 1104, receiving the electrical power demand signal may include receiving a change in a continuously received electrical power demand signal.

[0132] In response to receiving an electrical power demand signal in block 1104, or following maintaining the electrical power output of the power module 12 in block 1106, the control device may determine whether the electrical power demand of the IT loads 310 exceeds the electrical power output of the power modules 12 in the fuel cell IT grid system 300 in determination block 1108. The control device may determine the electrical output from a sensor at the DC power bus 304, from sensors at outputs of the power modules 12 or any component of the fuel cell IT grid system 300 electrically connecting the power modules 12 to the IT loads 310, and/or control devices of the power modules 12 or any component of the fuel cell IT grid system 300 electrically connecting the power modules 12 to the IT loads 310. In various embodiments, the control device may combine electrical outputs from the power modules 12 or the various components of the fuel cell IT grid system 300 to determine the electrical output of the power modules 12 in the fuel cell IT grid system 300. To determine whether the electrical power demand of the IT loads 310 exceeds the electrical power output of the power modules 12 in the fuel cell IT grid system 300, the control device may compare the electrical power demand and the electrical power output.

[0133] In response to determining that the electrical power demand does not exceed the electrical power output of the power modules 12 in the fuel cell IT grid system 300 (i.e., determination block 1108 = “No”), the control device may determine whether the electrical power output of the power modules 12 in the fuel cell IT grid system 300 exceeds the electrical power demand of the IT loads 310 in determination block 1110. The control device may determine whether the electrical power output of the power modules 12 in the fuel cell IT grid system 300 exceeds the electrical power demand of the IT loads 310 in a similar

manner as determining whether the electrical power demand of the IT loads 310 exceeds the electrical power output of the power modules 12 in the fuel cell IT grid system 300 in determination block 1108.

[0134] In response to determining that the electrical power output of the power modules 12 in the fuel cell IT grid system 300 exceeds the electrical power demand of the IT loads 310 (i.e., determination block 1110 = “Yes”), the control device may direct excess electrical power output of the power modules 12 in the fuel cell IT grid system 300 to any number and combination of load balancing loads 306 in block 1112. In various embodiments, the control device may control the flow of the excess electrical power output to a load balancing load 306 by controlling electrical connections to the load balancing load 306. The control device may control the electrical connections to the load balancing load 306 by directly controlling the electrical connections, by sending control signals to a control device of an electrical connection in the fuel cell IT grid system 300, and/or signaling to a control device of a load balancing load 306 configured to control an electrical connecting of the load balancing load 306 to the DC power bus 304. In various embodiments, the electrical connections to the load balancing load 306 may include a DC/DC converter 302, a DC/AC inverter 308, a DC disconnect 400, a bidirectional DC/AC inverter 800, and/or a switching mechanism configured to electrically connect and disconnect the load balancing load 306 to the DC power bus 304. The control device may be configured to determine an amount of excess electrical power output of the power modules 12. For example, the control device may be configured to determine a difference between the electrical power output of the power modules 12 and the electrical power demand of the IT loads 310.

[0135] In response to determining that the electrical power output of the power modules 12 in the fuel cell IT grid system 300 does not exceed the electrical power demand of the IT loads 310 (i.e., determination block 1108 = “No”), the control device may maintain the electrical power output of the power module 12 in block 1106.

[0136] In response to determining that the temperature of the power module 12 does not exceed the temperature threshold for the power module 12 (i.e., determination block 1102 = “No”), or in response to determining that the electrical power demand does exceed the electrical power output of the power modules 12 in the fuel cell IT grid system 300 (i.e., determination block 1108 = “Yes”), the control device may increase the electrical power output in the fuel cell IT grid system 300 in block 1114. In various embodiments, the control

device may increase the electrical power output in the fuel cell IT grid system 300 by increasing the electrical power output of the power modules 12 and/or power storage devices 402. In various embodiments, the control device may increase the electrical power output in the fuel cell IT grid system 300 by controlling a bidirectional DC/AC inverter 800 to supply electrical power from an electrical utility grid 802. In various embodiments, the control device may control the electrical power output of the power modules 12 and/or power storage devices 402 by directly controlling the power modules 12, the power storage devices 402, and/or electrical connections of the power modules 12 and/or power storage devices 402 to the DC power bus 304. In various embodiments, the control device 301 may control the electrical power output of the power modules 12 and/or power storage devices 402 by sending control signals to a controller of a power module 12, a power storage device 402, and/or an electrical connection of the power module 12 and/or power storage device 402 to the DC power bus 304. In various embodiments, the control device may control the electrical power output in the fuel cell IT grid system 300 by sending control signals to a controller of an electrical connection of the electrical utility grid 802 to the DC power bus 304. In various embodiments, an electrical connection may include a DC/DC converter 302, a DC/AC inverter 308, a DC disconnect 400, a bidirectional DC/AC inverter 800, and/or a switching mechanism configured to electrically connect and disconnect a power module 12, a power storage device 402, and/or a load balancing load 306 to the DC power bus 304.

[0137] In various embodiments, the method 1100 may continuously execute. In various embodiments, the method 1100 may continuously execute as a loop either continuously or periodically. In various embodiments, various blocks 1102-1114 may be executed at anytime in parallel with other blocks 1102-1114.

[0138] FIG. 12 illustrates an embodiment of a fuel cell IT grid system 1200 configured to provide hybrid DC electrical power to a load. A fuel cell IT grid system 1200 may include a variety of components, including one or more control devices 301 configured to receive data signals from and send control signals to any number and combination of power modules 12, a DC/DC converter 302, a DC power bus 304, a DC/AC inverter 308, an IT load 310 configured to operate using DC electrical current, a DC disconnect 400, a power storage device 402, a circuit breaker 404, a bidirectional DC/AC inverter 800, a static interrupter 1202, a trapped key interlock 1204, an AC/DC rectifier 1206, and a diode 1208. The control device(s) 301 may be any form of programmable computing device or system, such as a

server or overall system control device 301 that is configured to perform operations of various embodiments, including operations of the methods illustrated in FIGS. 14-16. FIG. 12 illustrates embodiments that are meant to be illustrative examples and not limiting of the scope of the claims.

[0139] A fuel cell IT grid system 1200 may include any number “N” of power modules 12 that may be configured as described herein with reference to FIG. 1, wherein N is an integer greater than or equal to 1, such as 1 to 24, e.g., 6 to 12. In various embodiments, the number of power modules 12 may be at least as many power modules 12 necessary to generate sufficient electrical power to satisfy at least a designated portion of electrical power demands of an IT load 310. In various embodiments, the number of power modules 12 may include any number of redundant power modules 12 so that in case of reduced or no electrical output from at least one power module 12, a redundant power module 12 may be used to continue supply of the portion of the electrical power demand of the IT load 310. Similarly, a power module may include a redundant fuel cell stack (not shown) so that in case of reduced or no electrical output from at least one fuel cell stack of a power module 12, a redundant fuel cell stack may be used to continue supply of the portion of the electrical power demand of the IT load 310. In some embodiments, a power module 12 may be configured to provide electrical power to a power storage device 402 in response to a charge level of the power storage device 402 falling short of a charge threshold amount. In some embodiments, a power module 12 may be configured to provide electrical power to an electrical utility in response to a charge level of the power storage device 402 exceeding the charge threshold amount and the power module 12 outputting more electrical power than the load demand of the IT load 310.

[0140] The power module 12 may be configured in a manner to provide a threshold amount of electrical power, which may be configured in terms of voltage, current, and/or power, to an IT load 310 via at least a DC bus 304 electrically connected to the power module via a DC/DC converter 302. The threshold amount of electrical power may be a portion of the designated portion of the electrical power demands of the IT load 310. In various embodiments, the power module 12 may be configured to provide electrical power to any combination of the IT load 310, a power storage device 402, an electrical utility, and an auxiliary/non-critical load via a rectifier path. The rectifier path may include any combination of components described herein electrically connected between an AC side of a

DC/AC inverter 308, which may be electrically connected to the power module 12 on the DC side of the DC/AC inverter 308, and the DC bus 304. Such components may include any combination of one or more circuit breakers 404, a static interrupt 1202, a trapped key interlock 1204, a bidirectional DC/AC inverter 800 electrically connected to a power storage device 402 on the DC side of the bidirectional DC/AC inverter 800, an AC/DC rectifier 1206, a DC disconnect 400 (e.g., DC disconnect B as illustrated in FIG. 12) electrically connecting the AC/DC rectifier 1206 to the DC bus 304, and one or more diodes 1208 electrically protecting the rectifier path from feedback from the DC bus 304. Such components may be electrically connected to each other via the AC bus 314. Thus, the rectifier path also includes the AC bus 314.

[0141] Control of the various components of the fuel cell IT grid system 1200 to direct the flow of electrical power output from the power module 12 to any combination of the IT load 310, a power storage device 402, an electrical utility, and an auxiliary/non-critical load may be based on any combination of readings of the electrical power output of the power module 12, the electrical power demands of the IT load 310, a charge level of the power storage device 402, and an electrical power output of the electrical utility. In various embodiments, the fuel cell IT grid system 1200 may include a control device 301 configured to control the various components of the fuel cell IT grid system 1200 to direct the flow of electrical power output from the power module 12. In various embodiments, control device 301 may be communicatively connected to any combination of the various components of the fuel cell IT grid system 1200 and configured to control and/or receive signals from the various components to direct the flow of electrical power output from the power module 12. Similarly, the control device 301 may be configured to direct the flow of electrical power output from the power storage device 402 and/or the electrical utility to the IT load 310.

[0142] A power module 12 may be electrically connected to a DC/DC converter 302, and may supply a DC electrical current to the DC/DC converter 302 via an electrical conduit. The DC/DC converter 302 may be configured to convert a DC electrical current received from an electrical power source to a higher or lower voltage. A DC/DC converter 302 may be unidirectional, configured to receive electrical power at an input end and to supply electrical power at an output end. In various embodiments, the electrical power source may include a power module 12. A DC/DC converter 302 may be electrically connected at an input end to a power module 12 and electrically connected to a DC power bus 304 at an

output end. A DC electrical current received by a DC/DC converter 302 from a power module 12 may be converted by the DC/DC converter 302 and supplied to a DC power bus 304. In various embodiments, a DC/DC converter 302 may be configured to supply a threshold amount of electrical power, which may be configured in terms of voltage, current, and/or power, to an IT load 310 at a designated voltage and/or amperage for the electrical power. The threshold amount of electrical power may be predetermined and based on electrical power capacity of a power module 12 and/or an electrical power demand of IT loads 310. A designated voltage and/or amperage for the electrical power supplied by a DC/DC converter 302 may be based on voltage and/or amperage for the electrical power supplied by other DC/DC converters 302 or on a DC power bus 304. A fuel cell IT grid system 1200 may include any number “M” of DC/DC converters 302 disposed between N power modules 12 and a DC power bus 304, wherein M is an integer greater than or equal to 1, and M may be the same number or a different number from N.

[0143] A DC power bus 304 may be configured as a common electrical conduit for multiple electrical power sources. In various embodiments, the electrical power sources may include any number and combination of a power module 12, a power storage device 402, an electrical utility, and/or a generator. A DC power bus 304 may be electrically connected to electrical power sources via other components of a fuel cell IT grid system 1200, such as DC/DC converters 302, DC/AC inverters 308, DC disconnects 400, circuit breakers 404, bidirectional DC/AC inverters 800, static interrupters 1202, and AC/DC rectifiers 1206. A DC power bus 304 may be configured to transmit electrical power to a load. In various embodiments, the load may include any number “Q” of IT loads 310, wherein Q is an integer greater than or equal to 1, and Q may be the same number or a different number from N or M. A DC power bus 304 may provide conduits for 3 phase electrical power, including a positive electrical power conduit, a neutral electrical power conduit, and a negative electrical power conduit.

[0144] A DC/AC inverter 308 may be configured to invert a DC electrical current received from an electrical power source to an AC electrical current. A DC/AC inverter 308 may be unidirectional, configured to receive electrical power at an input end and to supply electrical power at an output end. In various embodiments, the electrical power source may include a power module 12. A DC/AC inverter 308 may be electrically connected at an input end to a power module 12 and electrically connected to the rectifier path at an output end. A DC electrical current received by a DC/AC inverter 308 from an electrical power source may be

inverted by the DC/AC inverter 308 and supplied as AC electrical current to any combination of an IT load 310, a power storage device 402, an electrical utility, and an auxiliary/non-critical load via the rectifier path. In various embodiments, a DC/AC inverter 308 may be configured to supply a voltage and/or amperage for the electrical power produced by the power module 12 exceeding the threshold amount of electrical power. A fuel cell IT grid system 1200 may include any number “P” of DC/AC inverters 308, each disposed between a power module 12 and the rectifier path, wherein P is an integer greater than or equal to 1, and P may be the same number or a different number from N or M.

[0145] A bidirectional DC/AC inverter 800 may be configured to invert a DC electrical current received from an electrical power source to an AC electrical current and an AC electrical current received from an electrical power source to a DC electrical current. In various embodiments, the electrical power source may include a power module 12, a power storage device 402, and/or an electrical utility. A bidirectional DC/AC inverter 800 may be electrically connected at an AC end to an electrical power source, such as a power module 12 via a DC/AC inverter 308, and/or an electrical utility. A bidirectional DC/AC inverter 800 may also be electrically connected at an AC end to an IT load 310, such as via an AC/DC rectifier 1206. A bidirectional DC/AC inverter 800 may be electrically connected at a DC end to an electrical power source, such as a power storage device 402. A DC electrical current received by a bidirectional DC/AC inverter 800 from an electrical power source may be inverted by the bidirectional DC/AC inverter 800 and supplied to an IT load 310. An AC electrical current received by a bidirectional DC/AC inverter 800 from an electrical power source may be inverted by the bidirectional DC/AC inverter 800 and supplied to a power storage device 402. In various embodiments, a bidirectional DC/AC inverter 800 may be configured to supply a designated voltage and/or amperage for electrical power based on electrical power configuration of an IT load 310 and/or an electrical power demand of the IT load 310, and an electrical power on the rectifier path provided by the power module 12 and/or the electrical utility.

[0146] An IT load 310 may be configured to consume electrical power in a fuel cell IT grid system 1200. In various embodiments, electrical power may be provided to a fuel cell IT grid system 1200 by any number and combination of a power module 12, a power storage device 402, a generator, and/or an electrical utility. An IT load 310 may include any number and combination of computing devices, such as servers, network switches, routers,

supercomputers, and/or quantum computers, and/or cooling subsystem. A fuel cell IT grid system 1200 may include any number “Q” of IT loads 310, wherein Q is an integer greater than or equal to 1, and Q may be the same number or a different number from N or M. A voltage and/or amperage of electrical power required by an IT load 310 may be an electrical power demand of an IT load 310 on a fuel cell IT grid system 1200. Multiple IT loads 310 may require voltage and/or amperage of electrical power to be within specific requirements, and combined, these requirements present the electrical power demand of the IT load 310 on a fuel cell IT grid system 1200.

[0147] A power storage device 402 may include any number and combination of power storage devices 402. For example, a power storage device 402 may include any form of power storage including electromagnetic power storage, mechanical power storage, electrochemical power storage, chemical power storage, and/or thermal power storage. Some non-limiting examples include a capacitor, a flywheel, and/or a battery. A power storage device 402 may increase reliability of electrical power supply to an IT load 310 by providing redundant electrical power supply. In case of insufficient, reduced, or no electrical output from an electrical utility, a power storage device 402 may be used to augment or continue supply of an electrical power demand of an IT load 310. A power storage device 402 may be configured to store electrical power generated by a power module 12. A power storage device 402 may be configured to supply stored electrical power in response to generation of electrical power by power module(s) 12 below an electrical power demand of IT loads 310 of the fuel cell IT grid system 1200. A power storage device 402 may receive electrical power from an electrical power source (e.g., electrical utility and/or power module(s) 12) via the rectifier path and output the stored electrical power to a DC power bus 304 via the rectifier path.

[0148] An electrical protection component may include a fuse, a circuit breaker, and/or a switch. In various embodiments, an electrical protection component may include a DC disconnect 400. A DC disconnect 400 may be configured to connect and disconnect any number and combination of components of a fuel cell IT grid system 1200 from a DC power bus 304. A DC disconnect 400 may be configured with a threshold electrical power tolerance, which may be configured in terms of voltage, current, and/or power. A DC disconnect 400 may be normally configured to connect any number and combination of components of a fuel cell IT grid system 1200 to a DC power bus 304. Electrical power

supplied to a DC disconnect 400 exceeding its threshold electrical power tolerance may trigger disconnection of any number and combination of components of a fuel cell IT grid system 1200 from a DC power bus 304 by the DC disconnect 400. In various embodiments, any number and combination of “T” DC disconnects 400, wherein T is greater than or equal to 1, such as T equal to M+2, may selectively connect and disconnect any number and combination of components of a fuel cell IT grid system 1200 from the DC power bus 304. In various embodiments, components of a fuel cell IT grid system 1200 may include a power module 12. In various embodiments, components of a fuel cell IT grid system 1200 may include a power module 12 and components of the rectifier path.

[0149] In various embodiments, an electrical protection component may include a circuit breaker 404. A circuit breaker 404 may be configured to connect and disconnect any number and combination of components of a fuel cell IT grid system 1200 from each other, the electrical utility, the generator, and/or the ancillary/non-critical loads. A circuit breaker 404 may be configured with a threshold electrical power tolerance, which may be configured in terms of voltage, current, and/or power. A circuit breaker 404 (e.g., circuit breakers 1-P, circuit breaker A, circuit breaker C, circuit breaker D, and/or circuit breaker F as illustrated in FIG. 12) may be normally configured to connect any number and combination of components of a fuel cell IT grid system 1200 to each other, the electrical utility, and/or the ancillary/non-critical loads. Electrical power supplied to a circuit breaker 404 exceeding or falling short of its threshold electrical power tolerance may trigger disconnection of any number and combination of components of a fuel cell IT grid system 1200 from each other, the electrical utility, the generator, and/or the ancillary/non-critical loads by the circuit breaker 404. For example, failure of the electrical utility to provide electrical power to the fuel cell IT grid system 1200 may trigger any number of circuit breakers 404 (e.g., circuit breakers 1-P, circuit breaker A, circuit breaker B, and/or circuit breaker C) to disconnect the fuel cell IT grid system 1200 from the electrical utility and disconnect the power modules 12 from the rectifier path. In some embodiments, a circuit breaker 404 (e.g., circuit breaker B and/or circuit breaker E) may be normally configured to disconnect any number and combination of components of a fuel cell IT grid system 1200 from the electrical utility, and/or the generator. For example, a circuit breaker 404 (e.g., circuit breaker B) may be provided as a maintenance bypass for electrically connecting and disconnecting the electrical utility from components of the fuel cell IT grid system 1200, and the circuit breaker 404 may be manually switched. For further example, a circuit breaker 404 (e.g., circuit breaker E) may be provided to electrically

connect and disconnect a generator from the components of the fuel cell IT grid system 1200. The circuit breaker 404 may be conditionally switched to connect the generator in response to failure of the electrical utility and the power storage device 402 to provide power to the IT loads 310 and the demand of the IT loads 310 exceeding the output of the power modules 12.

[0150] In various embodiments, an electrical protection component may include a static interrupter 1202. The static interrupter 1202 may be configured to allow the flow of electrical power in a specific direction in response to a static interrupter threshold voltage and/or amperage of electrical power at one of the inputs of the static interrupter 1202. The static interrupter 1202 may continue to allow the flow of electrical power in one direction until receiving a static interrupter threshold voltage and/or amperage of electrical power at the opposite input, at which point the static interrupter 1202 may allow for an opposite flow of electrical power. The static interrupter 1202 may continue to allow the flow of electrical power in one direction until electrical power ceases to be provided to the static interrupter 1202, at which point the static interrupter 1202 may prevent any transmission of electrical power until a static interrupter threshold voltage and/or amperage of electrical power is applied to an input of the static interrupter. In various embodiments, the static interrupter 1202 may control the flow of electric power from the electrical utility to the fuel cell IT grid system 1200, and to the IT loads 310, and the static interrupter 1202 may control the flow of electric power from the fuel cell IT grid system 1200, and from the power modules 12, to the electrical utility. FIG. 13 illustrates an example of a static interrupter 1202 including opposing flow thyristors 1300 connected in parallel between the input/output ends of the static interrupter 1202. As discussed herein, a circuit breaker 404 (e.g., circuit breaker B) may be used as a maintenance bypass. In some embodiments, the static interrupter 1202 and the maintenance bypass circuit breaker 404 may be electrically connected in parallel so that electrical power may be manually controlled to bypass the static interrupter 1202.

[0151] In various embodiments, an electrical protection component may include a diode 1208. Diodes 1208 may be configured to allow electrical power to flow in a designated direction. Diodes 1208 may be electrically connected between the DC power bus 304 and the power modules 12 and/or the rectifier path to prevent feedback electrical flow to the power modules 12 and/or the rectifier path.

[0152] A trapped key interlock 1204, such as a Kirk interlock, may be implemented to control the ability of the electrical utility and a generator to provide power to the fuel cell IT

grid system 1200. The trapped key interlock 1204 may enforce that a circuit breaker 404 (e.g., circuit breaker C) configured to electrically connect the electrical utility and the fuel cell IT grid system 1200 and a circuit breaker 404 (e.g., circuit breaker E) configured to electrically connect the generator and the fuel cell IT grid system 1200 may not be closed at the same time. The trapped key interlock 1204 may require that a key be used to allow a change of state of each circuit breaker 400 connected to the trapped key interlock 1204, and that the key may be used to allow a change of state of one circuit breaker 404 at a time.

[0153] An AC/DC rectifier 1206 may be configured to rectify an AC electrical current received from an electrical power source to a DC electrical current. An AC/DC rectifier 1206 may be unidirectional, configured to receive electrical power at an input end and to supply electrical power at an output end. In various embodiments, the electrical power source may include a power module 12, a power storage device 402, an electrical utility, and/or a generator. An AC/DC rectifier 1206 may be electrically connected at an input end to the electrical utility and/or the generator via the rectifier path, and electrically connected to an IT load 310 at an output end via the DC power bus 304. An AC/DC rectifier 1206 may be electrically connected at an input end to the power module 12 and/or the power storage device 402 via a DC/AC inverter 308, 800 and the rectifier path, and electrically connected to an IT load 310 at an output end via the DC power bus 304. An AC electrical current received by an AC/DC rectifier 1206 from an electrical power source may be rectified by the AC/DC rectifier 1206 and supplied to the IT load 310 as a DC electrical current via the DC power bus 304. In various embodiments, an AC/DC rectifier 1206 may be configured to supply a voltage and/or amperage for electrical power produced by the power module 12 exceeding the threshold amount of electrical power. For example, a voltage set point of an AC/DC rectifier 1206 may be set below a voltage set point of the DC/DC converters 302 to encourage the threshold amount of electrical power to be provided to the IT loads 310 from the power modules 12 via the DC power bus 304 before additional electrical power is provided to the IT loads 310 via the AC/DC rectifier 1206.

[0154] FIG. 14 illustrates a method 1400 for managing hybrid DC power to a load according to various embodiments. The method 1400 may be implemented using one or more control devices 301 configured to receive signals from and/or send control signals to any number or combination of power modules 12, DC/DC converters 302, DC power busses 304, DC/AC inverters 308, IT loads 310, DC disconnects 400, power storage devices 402, circuit breakers

404, bidirectional DC/AC inverters 800, static interrupters 1202, trapped key interlocks 1204, AC/DC rectifiers 1206, diodes 1208, and rectifier paths. In order to encompass the alternative configurations enabled in various embodiments, the hardware implementing the method 1400 is referred to herein as a “control device.”

[0155] In determination block 1402, a control device may determine whether an electrical power is available from an electrical utility. In some embodiments, an electrical utility may fail and may not be able to provide electrical power to a fuel cell IT grid system 1200. In some embodiments, the control device may be configured to read electrical power levels, such as amperes or volts, provided to the fuel cell IT grid system 1200 to determine whether an electrical power is available from the electrical utility. In some embodiments, the control device may be informed of a state of the static interrupter 1202 that may indicate whether electrical power is being provided to the fuel cell IT grid system 1200 from the electrical utility via the static interrupter 1202 to determine whether an electrical power is available from the electrical utility.

[0156] In response to determining that an electrical power is available from the electrical utility (i.e., determination block 1402 = “Yes”), the control device may operate the fuel cell IT grid system 1200 in a normal mode in block 1404. Operation of the fuel cell IT grid system 1200 in the normal mode is described further herein with reference to the method 1500 of FIG. 15A and/or method 1550 of FIG. 15B.

[0157] In response to determining that an electrical power is not available from the electrical utility (i.e., determination block 1402 = “No”), the control device may operate the fuel cell IT grid system 1200 in a fail mode in block 1406. Operation of the fuel cell IT grid system 1200 in the fail mode is described further herein with reference to the method 1600 of FIG. 16.

[0158] In some embodiments, the control device may continually or periodically determine whether an electrical power is available from an electrical utility in determination block 1402. In some embodiments, the control device may determine whether an electrical power is available from an electrical utility in determination block 1402 in parallel with or upon completion of an operation of the fuel cell IT grid system 1200 in a normal mode in block 1404 or operation of the fuel cell IT grid system 1200 in a fail mode in block 1406.

[0159] FIG. 15A illustrates a method 1500 for normal mode management of hybrid DC power to a load according to various embodiments. The method 1500 may be implemented

using one or more control devices 301 configured to receive signals from and/or send control signals to any number or combination of power modules 12, DC/DC converters 302, DC power busses 304, DC/AC inverters 308, IT loads 310, DC disconnects 400, power storage devices 402, circuit breakers 404, bidirectional DC/AC inverters 800, static interrupters 1202, trapped key interlocks 1204, AC/DC rectifiers 1206, diodes 1208, and rectifier paths. In order to encompass the alternative configurations enabled in various embodiments, the hardware implementing the method 1500 is referred to herein as a “control device.” In some embodiments, the method 1500 may be implemented as part of block 1404 of the method 1400 described above with reference to FIG. 14.

[0160] In block 1502, the control device may provide output of the one or more power modules 12 up to a threshold amount of electrical power to an IT load 310 via a DC power bus 304. Since there may be one or more power modules 12 in the system 1200, the term “power module 12” will be used below for clarity to avoid repeating “one or more power modules 12”. However, it should be understood that “power module” below means the one or more power modules 12 located in the system 1200. As discussed herein, electrical power may be provided to an IT load 310 from a power module 12 via a DC/DC converter 302 electrically connecting the power module 12 to the DC power bus 304, and via the DC power bus 304 electrically connecting the DC/DC converter 302 to the IT load 310. The amount of electrical power a power module 12 may provide to an IT load 310 via the DC power bus 304 may be predetermined and set to a threshold amount of electrical power, which may be configured in terms of voltage, current, and/or power. A power module 12 may be configured to produce more than the threshold amount of electrical power, but the power module 12 and/or DC/DC converter 302 may be configured to limit the amount of electrical power provided to the IT load 310 from the power module 12 via the DC power bus 304 to the threshold amount of electrical power.

[0161] In block 1504, the control device may provide an electrical power output of a power module 12 exceeding the threshold amount of electrical power to a rectifier path. As discussed herein, a power module 12 may be electrically connected to a rectifier path via a DC/AC inverter 308. As a power module 12 and/or DC/DC converter 302 may be limited in the amount of electrical power output that can be output to the DC power bus 304, i.e., the threshold amount of electrical power, any additional power generated by a power module 12

may be inverted from DC electrical power to AC electrical power and provided to the rectifier path.

[0162] In determination block 1506, the control device may determine whether a load demand, also referred to herein as electrical power demand, from an IT load 310 is less than an output of a power module 12. An output of a power module 12 may be a total output combining the threshold amount of the electrical power output to the DC power bus 304 and an additional power generated by a power module 12 output to the rectifier path. The control device may have prior knowledge of or retrieve, such as from a power module 12 and/or a DC/DC converter 302, the threshold amount of electrical power a power module 12 may output to the IT load 310 via a DC power bus 304. The control device may sense and/or receive signals of an electrical power output of a power module 12 to a DC power bus 304 and/or a rectifier path. The control device may sense and/or receive signals of an electrical power demand of an IT load 310. The control device may compare the load demand from an IT load 310 to an output of a power module 12 to determine whether the load demand is less than the output of the power module 12.

[0163] In response to determining that a load demand from an IT load 310 is less than an output of a power module 12 (i.e., determination block 1506 = “Yes”), the control device may determine whether a power storage device 402 charge level (i.e., state of charge) exceeds a charge threshold amount in determination block 1508. The control device may be configured to test and/or receive signals indicating a charge level of a power storage device 402. The control device may compare a charge of a power storage device 402 and a charge threshold amount to determine whether the charge level exceeds the charge threshold amount. For example, the charge threshold amount may be a maximum charge level of the power storage device for storing electrical power, such as a greater than or equal to a 75% charge level, e.g., a 100% charge level.

[0164] In response to determining that a power storage device charge level does not exceed a charge threshold amount (i.e., determination block 1508 = “No”), the control device may charge a power storage device 402 using an output of a power module 12 on a rectifier path in block 1510. As discussed herein, electrical power output of a power module 12 exceeding a threshold electrical power amount may be output to a rectifier path. At least a portion of the electrical power output to a rectifier path by a power module 12 may not be needed to power an IT load 310. In response to a power storage device charge level not exceeding a

charge threshold amount, the control device may direct at least part of the electrical power output by a power module 12 via a rectifier path to the power storage device 402 to charge the power storage device 402. The electrical power on a rectifier path output by a power module 12 may be an AC electrical power inverted from a DC electrical power by a DC/AC inverter 308. A power storage device 402 may use DC electrical power to charge. A bidirectional DC/AC inverter 800 may be controlled by the control device to invert at least a portion of an AC electrical power to DC electrical power for charging a power storage device 402. The control device may repeatedly, periodically, and/or continuously determine whether the power storage device 402 charge level exceeds the charge threshold amount in determination block 1508. For example, the control device may repeatedly, periodically, and/or continuously determine whether the power storage device 402 charge level exceeds the charge threshold amount in determination block 1508 while the power storage device 402 charges in block 1510.

[0165] In response to determining that a power storage device charge level does exceed a charge threshold amount (i.e., determination block 1508 = “Yes”), the control device may provide an output of a power module 12 on a rectifier path to an electrical utility in block 1512. Electrical power generated by a power module 12 in excess of a threshold electrical power amount may be output to a rectifier path as an AC electrical power inverted from a DC electrical power by a DC/AC inverter 308. At least a portion of the electrical power output to a rectifier path by a power module 12 may not be needed to power an IT load 310. The portion of the electrical power output to a rectifier path by a power module 12 not needed to power an IT load 310 may be output to an electrical utility.

[0166] In response to determining that a load demand from an IT load 310 is not less than an output of a power module 12 (i.e., determination block 1506 = “No”), the control device may provide an electrical power output of power module 12 on a rectifier path to an IT load 310 in block 1514. As long as a power module 12 produces more electrical power than a threshold amount of electrical power, the power module 12 may output electrical power to a rectifier path. The electrical power output by the power module to the rectifier path may be used to power an IT load 310.

[0167] In determination block 1516, the control device may determine whether a power storage device charge level exceeds a charge output threshold amount. For example, the charge output threshold amount may be a minimum change level of the power storage device

suitable for providing electrical power from the power storage device to an IT load 310, such as a 50% charge level. The control device may be configured to test and/or receive signals indicating a charge level of a power storage device 402. The control device may compare a charge of a power storage device 402 and a charge output threshold amount to determine whether the charge level exceeds the charge output threshold amount. By virtue of determining that a load demand from an IT load 310 is not less than an output of a power module 12 in determination block 1506, the control device may be aware that there is insufficient electrical power being provided by a power module 12 to satisfy the electrical power demands of an IT load 310, which may need to be supplemented.

[0168] In response to determining that a power storage device charge level does not exceed a charge output threshold amount (i.e., determination block 1516 = “No”), the control device may provide an output of an electrical utility to an IT load 310 via a rectifier path in block 1518. To supplement the electrical power output by a power module 12 that is insufficient to satisfy the electrical power demands of an IT load 310, the control device may calculate and provide an amount of electrical power from an electrical utility to alleviate the shortfall of the electrical power output by the power module 12. The control device may be configured to read and/or receive signals indicating the electrical power output by a power module 12 to an IT load 310 and an electrical power demand of an IT load 310, and calculate how much electrical power is needed from an electrical utility to satisfy the electrical power demand of the IT load 310. The control device may control components of a rectifier path to provide an amount of electrical power output from an electrical utility to an IT load 310.

[0169] In response to determining that a power storage device charge level does exceed a charge output threshold amount (i.e., determination block 1516 = “Yes”), the control device may provide an output of the power storage device 402 to an IT load 310 via a rectifier path in block 1520. To supplement the electrical power output by a power module 12 that is insufficient to satisfy the electrical power demands of an IT load 310, the control device may calculate and provide an amount of electrical power from a power storage device 402 to alleviate the shortfall of the electrical power output by the power module 12. The control device may be configured to read and/or receive signals indicating the electrical power output by a power module 12 to an IT load 310 and an electrical power demand of an IT load 310, and calculate how much electrical power is needed from a power storage device 402 to satisfy the electrical power demand of the IT load 310. The control device may control

components of a rectifier path to provide an amount of electrical power output from a power storage device 402 to an IT load 310. The control device may repeatedly, periodically, and/or continuously determine whether the power storage device charge level exceeds the charge output threshold amount in determination block 1516. For example, the control device may repeatedly, periodically, and/or continuously determine whether the power storage device charge level exceeds the charge output threshold amount in determination block 1516 while the power storage device 402 outputs electrical power to the IT load 310 via the rectifier path in block 1520.

[0170] FIG. 15B illustrates a method 1550 for normal mode management of hybrid DC power to a load according to another embodiment. The method 1550 may be implemented using one or more control devices 301 configured to receive signals from and/or send control signals to any number or combination of power modules 12, DC/DC converters 302, DC power busses 304, DC/AC inverters 308, IT loads 310, DC disconnects 400, power storage devices 402, circuit breakers 404, bidirectional DC/AC inverters 800, static interrupters 1202, trapped key interlocks 1204, AC/DC rectifiers 1206, diodes 1208, and rectifier paths. In order to encompass the alternative configurations enabled in various embodiments, the hardware implementing the method 1550 is referred to herein as a “control device.” In some embodiments, the method 1550 may be implemented as part of block 1404 of the method 1400 with reference to FIG. 14.

[0171] In the method of the alternative embodiment of FIG. 15B, blocks 1502, 1504, 1508, 1510, 1512, 1516, 1518, and 1520 may be implemented as described above in same numbered blocks of the method 1500 of FIG. 15A.

[0172] In block 1502, the control device may provide output of power modules 12 up to a threshold amount of electrical power to an IT load 310 via a DC power bus 304.

[0173] In determination block 1552, the control device may determine whether a load demand, also referred to herein as electrical power demand, of the IT load 310 is less than a threshold amount of electrical power. As discussed herein, a power module 12 and/or DC/DC converter 302 may be limited in the amount of electrical power output that can be output to the DC power bus 304, i.e., the threshold amount of electrical power. The threshold amount of electrical power may be predetermined and based on electrical power capacity of a power module 12 and/or an electrical power demand of the IT load 310. For example, the

threshold amount of electrical power may be an amount of electrical power that may satisfy at least a designated portion of a typical electrical power demand of the IT load 310. The control device may have prior knowledge of or retrieve, such as from a power module 12 and/or a DC/DC converter 302, the threshold amount of electrical power a power module 12 may output to the IT load 310 via a DC power bus 304. The control device may sense and/or receive signals of an electrical power demand of an IT load 310. The control device may compare the load demand of the IT load to the threshold amount of electrical power to determine whether the load demand of the IT load 310 is less than the threshold amount of electrical power.

[0174] In response to determining that the load demand of the IT load 310 is less than the threshold amount of electrical power (i.e., determination block 1552 = “Yes”), the control device may provide the electrical power output of the power module 12 to the rectifier path that is in excess of the electrical power output provided to the IT load 310 via the DC bus 304 in block 1554. As discussed herein, a power module 12 may be electrically connected to a rectifier path via a DC/AC inverter 308. The additional electrical power, above the load demand of the IT load 310, generated by the power module 12 may be inverted from DC electrical power to AC electrical power and provided to the rectifier path.

[0175] In determination block 1508, the control device may determine whether a power storage device 402 charge level (i.e., state of charge) exceeds a charge threshold amount. In response to determining that a power storage device charge level does not exceed a charge threshold amount (i.e., determination block 1508 = “No”), the control device may charge a power storage device 402 using an output of a power module 12 on a rectifier path in block 1510. The control device may repeatedly, periodically, and/or continuously determine whether the power storage device 402 charge level exceeds the charge threshold amount in determination block 1508. In response to determining that a power storage device charge level does exceed a charge threshold amount (i.e., determination block 1508 = “Yes”), the control device may provide an output of a power module 12 on a rectifier path to an electrical utility in block 1512.

[0176] In response to determining that the load demand of the IT load 310 is not less than the threshold amount of electrical power (i.e., determination block 1552 = “No”), the control device may provide an electrical power output of a power module 12 exceeding the threshold amount of electrical power to a rectifier path in block 1504.

[0177] In block 1556, the control device may provide at least part (i.e., some or all) of the output of the power module 12 on the rectifier path to the IT load 310. As the load demand of the IT load 310 exceeds the threshold amount of electrical power, i.e., the amount of electrical power provided to the IT load 310 from the power module 12 via the DC power bus 304, the additional power provided from the power module 12 to the rectifier path may be used to satisfy the load demand of the IT load 310. Depending on the load demand of the IT load 310 and the amount of electrical power on the rectifier path provided by the power module 12, some or all of the electrical power on the rectifier path provided by the power module 12 may be provided to the IT load 310. The rectifier path may be electrically connected to the IT load via an AC/DC rectifier 1206, which may convert the AC electrical current on the rectifier path to a DC electrical current provided to the IT load 310.

[0178] In determination block 1558, the control device may determine whether the load demand of the IT load 310 is satisfied. The control device may control, predetermine, and/or sense the load demand of the IT load 310, and the amount of electrical power provided to the IT load 310 via the DC bus 304, i.e., the threshold amount of electrical power, and via the rectifier path, as in block 1556. The control device may compare the load demand with the sum of the electrical power provided to the IT load 310 via the DC bus 304 and the rectifier path to determine whether the load demand of the IT load 310 is satisfied.

[0179] In response to determining that the load demand of the IT load 310 is satisfied (i.e., determination block 1558 = “Yes”), the control device may determine whether there is electrical power available on the rectifier path in determination block 1560. As discussed above, the control device may control, predetermine, and/or sense the amount of electrical power provided to the IT load 310 via the rectifier path, as in block 1556. In some embodiments, the control device may also control, predetermine, and/or sense the amount of electrical power provided to the rectifier path from the power module 12, as in block 1504. The control device may calculate the amount of power remaining on the rectifier path from the amount of electrical power provided to the rectifier path from the power module 12 and the amount of electrical power provided to the IT load 310 from the rectifier path. In some embodiments, the control device may also control, predetermine, and/or sense the amount of electrical power remaining on the rectifier path after providing electrical power to the IT load 310 from the rectifier path. In response to determining that there is not electrical power available on the rectifier path (i.e., determination block 1560 = “No”), the control device may

repeatedly, periodically, and/or continually determine whether the load demand of the IT load 310 is satisfied in determination block 1558.

[0180] In response to determining that there is electrical power available on the rectifier path (i.e., determination block 1560 = “Yes”), the control device may determine whether a power storage device 402 charge level (i.e., state of charge) exceeds a charge threshold amount, in determination block 1508. In response to determining that a power storage device charge level does not exceed a charge threshold amount (i.e., determination block 1508 = “No”), the control device may charge a power storage device 402 using an output of a power module 12 on a rectifier path in block 1510. The control device may repeatedly, periodically, and/or continuously determine whether the power storage device 402 charge level exceeds the charge threshold amount in determination block 1508. In response to determining that a power storage device charge level does exceed a charge threshold amount (i.e., determination block 1508 = “Yes”), the control device may provide an output of a power module 12 on a rectifier path to an electrical utility in block 1512.

[0181] In response to determining that the load demand of the IT load 310 is not satisfied (i.e., determination block 1558 = “No”), the control device may determine whether a power storage device 402 charge level exceeds a charge output threshold amount in determination block 1516. In response to determining that a power storage device charge level does not exceed a charge output threshold amount (i.e., determination block 1516 = “No”), the control device may provide an output of an electrical utility to an IT load 310 via a rectifier path in block 1518. In response to determining that a power storage device charge level does exceed a charge output threshold amount (i.e., determination block 1516 = “Yes”), the control device may provide an output of the power storage device 402 to an IT load 310 via a rectifier path in block 1520. The control device may repeatedly, periodically, and/or continuously determine whether the power storage device charge level exceeds the charge output threshold amount in determination block 1516.

[0182] FIG. 16 illustrates a method 1600 for fail mode management of hybrid DC power to a load according to various embodiments. The method 1600 may be implemented using one or more control devices 301 configured to receive signals from and/or send control signals to any number or combination of power modules 12, DC/DC converters 302, DC power busses 304, DC/AC inverters 308, IT loads 310, DC disconnects 400, power storage devices 402, circuit breakers 404, bidirectional DC/AC inverters 800, static interrupters 1202, trapped key

interlocks 1204, AC/DC rectifiers 1206, diodes 1208, and rectifier paths. In order to encompass the alternative configurations enabled in various embodiments, the hardware implementing the method 1600 is referred to herein as a “control device.” In some embodiments, the method 1600 may be implemented as part of block 1406 of the method 1400 described above with reference to FIG. 14.

[0183] In block 1602, the control device may provide an output of a power module 12 up to a threshold amount of electrical power to the IT load 310 via a DC power bus 304. As discussed herein, electrical power may be provided to an IT load 310 from a power module 12 via a DC/DC converter 302 electrically connecting the power module 12 to the DC power bus 304, and via the DC power bus 304 electrically connecting the DC/DC converter 302 to the IT load 310. The amount of electrical power a power module 12 may provide to an IT load 310 via the DC power bus 304 may be predetermined and set to a threshold amount of electrical power, which may be configured in terms of voltage, current, and/or power. A power module 12 may be configured to produce more than the threshold amount of electrical power, but the power module 12 and/or DC/DC converter 302 may be configured to limit the amount of electrical power provided to the IT load 310 from the power module 12 via the DC power bus 304 to the threshold amount of electrical power.

[0184] In block 1604, the control device may isolate a power module 12 from a rectifier path and a fuel cell IT grid system 1200 from an electrical utility when the electrical utility fails (i.e., stops supplying power). A power module 12 may be electrically connected to a rectifier path via other components of a fuel cell IT grid system 1200, including a DC/AC inverter 308 and any number of circuit breakers 404 (e.g., circuit breaker 1-P and/or circuit breaker A as illustrated in FIG. 12). To isolate a power module 12 from a rectifier path, the control device may control the DC/AC inverter 308 to prevent output of the DC/AC inverter 308 to the rectifier path and/or control at least one circuit breaker 404 electrically connecting the power module 12 to the rectifier path to open. A fuel cell IT grid system 1200 may be electrically connected to an electrical utility via a static interrupter 1202 and a circuit breaker 404 (e.g., circuit breaker C as illustrated in FIG. 12). To isolate a fuel cell IT grid system 1200 from an electrical utility the control device may prevent operation of a static interrupter 1202 and/or open the circuit breaker 404. In some embodiments, the static interrupter 1202 may cease operation before opening the circuit breaker 404. In some embodiments, the circuit breaker

404 may be normally configured to be closed and is only open when the utility is not available to supply power.

[0185] In determination block 1606, the control device may determine whether an electrical power demand of an IT load 310 exceeds a threshold amount of electrical power a power module 12 may output to the IT load 310 via a DC power bus 304. The control device may have prior knowledge of or retrieve, such as from a power module 12 and/or a DC/DC converter 302, the threshold amount of electrical power a power module 12 may output to the IT load 310 via a DC power bus 304. The control device may sense and/or receive signals of an electrical power demand of an IT load 310. The control device may compare the threshold amount of electrical power and the electrical power demand to determine whether the electrical power demand of the IT load 310 exceeds the threshold amount of electrical power the power module 12 may output to the IT load 310 via the DC power bus 304.

[0186] In response to determining that an electrical power demand of an IT load 310 does not exceed a threshold amount of electrical power a power module 12 may output to the IT load 310 via a DC power bus 304 (i.e., determination block 1606 = “No”), the control device may provide an output of a power module 12 up to a threshold amount of electrical power to an IT load 310 via a DC power bus 304 in block 1620.

[0187] In response to determining that an electrical power demand of an IT load 310 exceeds a threshold amount of electrical power a power module 12 may output to the IT load 310 via a DC power bus 304 (i.e., determination block 1606 = “Yes”), the control device may provide an output of a power storage device 402 to an IT load 310 via a rectifier path in block 1608. The control device may be configured to sense and/or receive signals of an electrical power demand of an IT load 310. By comparing the electrical power demand of an IT load 310 with the threshold amount of electrical power output by a power module 12 to the IT load 310, the control device may calculate an amount of power needed to satisfy the electrical power demand of the IT load 310. The control device may control a power storage device 402 and/or a bidirectional DC/AC inverter 800 to output from the power storage device 402 to the AC bus 314 a calculated amount of power needed to satisfy an electrical power demand of an IT load 310.

[0188] In determination block 1610, the control device may determine whether an output from a power storage device 402 to an IT load 310 is stable. The control device may be

configured to sense and/or receive signals of an amount and/or quality of electrical power that is available on a rectifier path to provide to an IT load 310 from a power storage device 402. The control device may be configured to sense and/or receive signals of an electrical power demand of an IT load 310. By comparing the electrical power demand of an IT load 310 with the threshold amount of electrical power output by a power module 12 to the IT load 310 and the electrical power available from a power storage device 402 on a rectifier path, the control device may determine whether the electrical power demand of the IT load 310 is being satisfied. When the electrical power demand of the IT load 310 is being satisfied by the electrical power provided to the IT load 310 by the power module 12 via the DC power bus 304 and by the power storage device 402 via the rectifier path, the control device may determine that output from a power storage device 402 to an IT load 310 is stable. In other words, the control device may determine that an AC grid on the rectifier path, created by the power output of the power storage device 402 converted from DC to AC by a bidirectional DC/AC inverter 800, is stable. In some embodiments, the control device may also compare qualities of the AC electrical power on the rectifier path, such as amplitude, to qualitative thresholds to determine whether output from a power storage device 402 to an IT load 310 is stable.

[0189] In response to determining that the output from a power storage device 402 to an IT load 310 is not stable (i.e., determination block 1610 = “No”), the control device may provide an output of a power storage device 402 to an IT load 310 via a rectifier path in block 1608. In some embodiments, the control device may increase the power output of the power storage device 402 to stabilize to the AC grid on the rectifier path created by the power output of the power storage device 402 converted from DC to AC by the bidirectional DC/AC inverter 800. In response to determining that the output from a power storage device 402 to an IT load is stable (i.e., determination block 1610 = “Yes”), the control device may provide an output of a power module 12 exceeding a threshold amount of electrical power to a rectifier path in block 1612. As discussed herein, a power module 12 and/or DC/DC converter 302 may be limited to a threshold amount of electrical power that may be output to an IT load 310 via a DC power bus 304, and any electrical power generated by the power module 12 in excess of the threshold amount of electrical power may be inverted to AC electrical power by a DC/AC inverter 308 and output to a rectifier path. In some embodiments, to provide an output of a power module 12 exceeding a threshold amount of electrical power to a rectifier path, the control device may undo the isolation of a power module 12 from a rectifier path in

block 1604. To undo the isolation, or reconnect a power module 12 to a rectifier path, the control device may control a DC/AC inverter 308 to allow output of the DC/AC inverter 308 to the rectifier path and/or control at least one circuit breaker 404 (e.g., circuit breakers 1-P and/or circuit breaker A as illustrated in FIG. 12) electrically connecting the power module 12 to the rectifier path to close.

[0190] In determination block 1614, the control device may determine whether the remaining electrical power demand of an IT load 310 (i.e., the demand that is in excess of the output of the power module 12 on the DC bus 304) is satisfied by the output of a power module 12 on the rectifier path. An output of a power module 12 may be a total output combining a threshold amount of the electrical power output to the DC power bus 304 and an additional power generated by a power module 12 output to the rectifier path. The control device may have prior knowledge of or retrieve, such as from a power module 12 and/or a DC/DC converter 302, the threshold amount of electrical power a power module 12 may output to the IT load 310 via a DC power bus 304. The control device may sense and/or receive signals of an electrical power output of a power module 12 to a DC power bus 304 and/or a rectifier path. The control device may sense and/or receive signals of an electrical power demand of an IT load 310. The control device may compare the threshold amount of electrical power and/or output amount of a power module 12 to a DC power bus 304 and/or a rectifier path with the electrical power demand to determine whether the electrical power demand of the IT load 310 is less than the electrical power output of the power module 12.

[0191] In response to determining that the remaining electrical power demand of the IT load 310 is not satisfied by the output of a power module 12 on the rectifier path (i.e., determination block 1614 = “No”), the control device may provide an electrical power output of a power module 12 and continue to provide the electrical power output of the power storage device 402 on the rectifier path to the IT load 310 in block 1616. When an electrical power demand of an IT load 310 is greater than an output of a power module 12, an output of a power module 12 may be fully consumed by an IT load 310. Thus, the control device may provide the excess electrical power, above the threshold amount of electrical power a power module 12 may output to the IT load 310 via a DC power bus 304, from both the power storage device 402 (as in block 1608) and from the power module 12 to the IT load 310 via the rectifier path. The control device may reduce the electrical power from the power storage device 402 as compared to prior to providing the electrical power output of the power module

12 as the power storage device 402 may no longer need to support the same amount of the load demand. The control device may repeatedly, periodically, and/or continually determine whether an electrical power demand of an IT load 310 is satisfied by the output of the power module 12 on the rectifier path in determination block 1614.

[0192] In response to determining that the remaining electrical power demand of the IT load 310 is satisfied by the output of the power module 12 on the rectifier path (i.e., determination block 1614 = “Yes”), the control device may provide all or part of the output from the power module 12 on the rectifier path to the IT load 310 to satisfy the remaining power demand of the IT load 310 in block 1618. In block 1620, the control device may control the AC/DC inverter to stop providing output of the power storage device 402 to the IT load 310 via the AC bus 314 and the AC/DC rectifier 1260. In block 1622, the control device may determine whether the power storage device 402 state of charge exceeds a charge threshold. In other words, the control device may determine whether the power storage device 402 needs to be recharged if the state of charge of the device 402 is below a certain threshold (e.g., below 100%, such as below 75%).

[0193] If the control device determines that the power storage device 402 needs to be recharged (i.e., charge does not exceed charge threshold and determination block 1622 = “No”) and that there is remaining output of the power module 12 on the rectifier path in excess of the amount used to satisfy the remaining electrical power demand of the IT load 310, then in block 1624, the control device may charge the power storage device 402 using the remaining output of the power module 12 on the rectifier path until the power storage device 402 reaches a charge threshold (i.e., until device 402 is fully charged). In block 1624, the control device may control the DC/AC inverter 800 to provide the remaining output of the power module 12 on the rectifier path to the power storage device 402. In other words, the power flows from the AC bus 314 to the power storage device 402 through the DC/AC inverter 800. The process then returns to block 1614 until the failure mode is terminated and normal mode is restored.

[0194] If the control device determines that there is no remaining output of the power module 12 on the rectifier path in excess of the amount used to satisfy the remaining electrical power demand of the IT load 310, then the process returns to block 1614 until the failure mode is terminated and normal mode is restored. If the control device determines that the power storage device 402 does not need to be recharged (i.e., charge exceeds the charge threshold

and determination block 1622 = “Yes”) then the process returns to block 1614 until the failure mode is terminated and normal mode is restored

[0195] The foregoing method descriptions and diagrams are provided merely as illustrative examples and are not intended to require or imply that the steps of the various embodiments must be performed in the order presented. As will be appreciated by one of skill in the art the order of steps in the foregoing embodiments may be performed in any order. Further, words such as “thereafter,” “then,” “next,” etc. are not intended to limit the order of the steps; these words are simply used to guide the reader through the description of the methods. One or more diagrams have been used to describe exemplary embodiments. The use of diagrams is not meant to be limiting with respect to the order of operations performed. The foregoing description of exemplary embodiments has been presented for purposes of illustration and of description. It is not intended to be exhaustive or limiting with respect to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the disclosed embodiments. It is intended that the scope of the invention be defined by the claims appended hereto and their equivalents.

[0196] Control elements, including the control device 301 as well as connected controllers described herein, may be implemented using computing devices (such as computer) that include programmable processors, memory and other components that have been programmed with instructions to perform specific functions or may be implemented in processors designed to perform the specified functions. A processor may be any programmable microprocessor, microcomputer or multiple processor chip or chips that can be configured by software instructions (applications) to perform a variety of functions, including the functions of the various embodiments described herein. In some computing devices, multiple processors may be provided. Typically, software applications may be stored in the internal memory before they are accessed and loaded into the processor. In some computing devices, the processor may include internal memory sufficient to store the application software instructions.

[0197] The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their

functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

[0198] The hardware used to implement the various illustrative logics, logical blocks, modules, and circuits described in connection with the aspects disclosed herein may be implemented or performed with a control device that may be or include a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but, in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. Alternatively, some blocks or methods may be performed by circuitry that is specific to a given function.

[0199] The preceding description of the disclosed embodiments is provided to enable any person skilled in the art to make or use any of the described embodiments. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the scope of the disclosure. Thus, the claims are not intended to be limited to the embodiments shown herein but are to be accorded the widest scope consistent with the claim language and the principles and novel features disclosed herein.

WHAT IS CLAIMED IS:

1. A system, comprising:

- a plurality of power modules each including at least one fuel cell;
- a plurality of direct current (DC)/DC converters each having an input end and an output end, and each electrically connected to a power module of the plurality of power modules at the input end;
- a DC power bus electrically connected to the plurality of DC/DC converters in parallel at the output end and electrically connectable to a load;
- a plurality of DC/alternating current (AC) inverters each having a DC end and an AC end, and each electrically connected to a power module of the plurality of power modules at the DC end;
- a rectifier path electrically connected to the plurality of DC/AC inverters at the AC end in parallel;
- an AC/DC rectifier having an AC end and a DC end, and electrically connected to the rectifier path at the AC end and to the DC power bus at the DC end; and
- a control device communicatively connected to the plurality of DC/DC converters and to the plurality of DC/AC inverters, and configured with control device executable instructions to cause the control device to:
 - provide a first electrical power up to a threshold amount of power to the load from the plurality of power modules via the plurality of DC/DC converters and the DC power bus;
 - determine whether electrical power from a utility is available; and
 - provide a second electrical power from the plurality of power modules the rectifier path via the plurality of DC/AC inverters in response to determining that the electrical power from the utility is available, wherein the second electrical power comprises electrical power generated by the plurality of power modules in excess of the threshold amount of electrical power.

2. The system of claim 1, wherein the control device is configured with control device executable instructions to further cause the control device to:

- determine whether a load demand of the load is less than the first and second electrical power output from the plurality of power modules; and

if the load demand of the load is not less than the first and second electrical power output from the plurality of power modules, then provide at least a portion of the second electrical power to the load via the rectifier path.

3. The system of claim 2, further comprising:

a bidirectional DC/AC inverter having a first end and a second end, and electrically connected to the rectifier path at the first end; and

a power storage device electrically connected to the bidirectional DC/AC inverter at the second end;

wherein the control device is communicatively connected to the bidirectional DC/AC inverter and configured with control device executable instructions to further cause the control device to:

determine whether the power storage device charge exceeds an output threshold;

provide electrical power from the utility to the load via the rectifier path if the power storage device charge does not exceed the output threshold; and

provide electrical power from the power storage device to the load via the rectifier path if the power storage device charge exceeds the output threshold.

4. The system of claim 3, wherein the control device is configured with control device executable instructions to further cause the control device to:

if the load demand of the load is less than the first and second electrical power output from the plurality of power modules, then determine whether the power storage device charge exceeds a charge threshold;

if the power storage device charge exceeds the charge threshold, then charge the charge storage device using the second electrical power on the rectifier path; and

if the power storage device charge does not exceed the charge threshold, then provide any remaining second electrical power to the utility via the rectifier path.

5. The system of claim 1, wherein the control device is configured with control device executable instructions to further cause the control device to:

determine whether a load demand of the load is less than the threshold amount of power;

if the load demand is less than the threshold amount of power, then provide the second electrical power which exceeds the load demand to the rectifier path, determine

whether the power storage device charge exceeds a charge threshold, if the power storage device charge exceeds the charge threshold, then charge the charge storage device using the second electrical power, and if the power storage device charge does not exceed the charge threshold, then provide any remaining second electrical power to the utility via the rectifier path;

if the load demand is not less than the threshold amount of power, then provide at least a portion of the second electrical power on the rectifier path to the load.

6. The system of claim 1, further comprising:

a static interrupter having a first end and a second end, the static interrupter electrically connected to the rectifier path at the first end, and electrically connectable to the utility at the second end; and

a circuit breaker having a first end and a second end, the circuit breaker electrically connected to the plurality of DC/AC inverters at the first end and electrically connected to the rectifier path at the second end; and

wherein the control device is communicatively connected to the static interrupter and to the circuit breaker, and configured with control device executable instructions to further cause the control device to:

in response to determining that the electrical power from the utility is not available:

electrically disconnect the plurality of DC/AC inverters from the rectifier path by opening the circuit breaker; and

electrically disconnect the system from the utility by preventing electrical power to flow through the static interrupter.

7. The system of claim 6, further comprising:

a bidirectional DC/AC inverter having a first end and a second end, and electrically connected to the rectifier path at the first end;

a power storage device electrically connected to the bidirectional DC/AC inverter at the second end; and

wherein the control device is communicatively connected to the bidirectional DC/AC inverter and to the AC/DC rectifier, and configured with control device executable instructions to further cause the control device to:

determine whether a load demand of the load exceeds the threshold electrical power; and

provide a third electrical power from the power storage device to the load via the bidirectional DC/AC inverter, the rectifier path, and the AC/DC rectifier in response to determining that the load demand of the load exceeds the threshold electrical power.

8. The system of claim 7, wherein the control device is configured with control device executable instructions to further cause the control device to:

determine whether the third electrical power provided to the load is stable; and
in response to determining that the third electrical power provided to the load is stable:

electrically connect the plurality of DC/AC inverters to the rectifier path by closing the circuit breaker; and

provide at least a first part of the second electrical power to the load via the rectifier path and the AC/DC rectifier.

9. The system of claim 8, wherein the control device is configured with control device executable instructions to further cause the control device to:

determine whether the load demand of the load is satisfied by the second electrical power;

in response to determining that the load demand of the load is satisfied by the second electrical power:

cease providing the third electrical power to the load; and

provide the second electrical power on the rectifier path to the load; and

in response to determining that the load demand of the load is not satisfied by the second electrical power, provide the second and the third electrical power on the rectifier path to the load.

10. The system of claim 1, further comprising:

a first circuit breaker having a first end and a second end, the first circuit breaker electrically connected to the rectifier path at the first end and electrically connectable to the electric power utility at the second end;

a second circuit breaker having a first end and a second end, the second circuit breaker electrically connected to the rectifier path at the first end in parallel with the first circuit breaker, and electrically connectable to a generator at the second end;

a trapped key interlock configured to concurrently open the first circuit breaker and close the second circuit breaker;

a first plurality of diodes electrically connected between the plurality of DC/DC converters and the DC power bus, and configured to prevent feedback to the DC/DC converters; and

a second plurality of diodes electrically connected between the AC/DC rectifier and the DC power bus, and configured to prevent feedback to the AC/DC rectifier.

11. A method of operating a power generation system, comprising:

providing a first electrical power up to a threshold amount of power to a load from at least one power module via a plurality of DC/DC converters and a DC power bus;

determining whether electrical power from a utility is available; and

providing a second electrical power from the at least one power module to a rectifier path via a plurality of DC/AC inverters in response to determining that the electrical power from the utility is available, wherein the second electrical power comprises electrical power generated by the at least one power module in excess of the threshold amount of electrical power.

12. The method of claim 11, further comprising

determining whether a load demand of the load is less than the first and second electrical power output from the at least one power module; and

if the load demand of the load is not less than the first and second electrical power output from the at least one power module, then providing at least a portion of the second electrical power to the load via the rectifier path.

13. The method of claim 12, further comprising:

determining whether a power storage device charge exceeds an output threshold;

providing electrical power from the utility to the load via the rectifier path if the power storage device charge does not exceed the output threshold; and

providing electrical power from the power storage device to the load via the rectifier path if the power storage device charge exceeds the output threshold.

14. The method of claim 13, further comprising:

if the load demand of the load is less than the first and second electrical power output from the at least one power module, then determining whether the power storage device charge exceeds a charge threshold;

if the power storage device charge exceeds the charge threshold, then charging the charge storage device using the second electrical power on the rectifier path; and

if the power storage device charge does not exceed the charge threshold, then providing any remaining second electrical power to the utility via the rectifier path.

15. The method of claim 11, further comprising:

determining whether a load demand of the load is less than the threshold amount of power;

if the load demand is less than the threshold amount of power, then providing the second electrical power which exceeds the load demand to the rectifier path, determining whether the power storage device charge exceeds a charge threshold, if the power storage device charge exceeds the charge threshold, then charging the charge storage device using the second electrical power, and if the power storage device charge does not exceed the charge threshold, then providing any remaining second electrical power to the utility via the rectifier path;

if the load demand is not less than the threshold amount of power, then providing at least a portion of the second electrical power on the rectifier path to the load.

16. The method of claim 11, further comprising:

in response to determining that the electrical power from the utility is not available:

electrically disconnecting a plurality of DC/AC inverters from the rectifier path by opening a circuit breaker; and

electrically disconnecting the power generation system from the utility by preventing electrical power to flow through a static interrupter.

17. The method of claim 16, further comprising:

determining whether a load demand of the load exceeds the threshold electrical power; and

providing a third electrical power from a power storage device to the load via a bidirectional DC/AC inverter, the rectifier path, and an AC/DC rectifier in response to determining that the load demand of the load exceeds the threshold electrical power.

18. The method of claim 17, further comprising:

determining whether the third electrical power provided to the load is stable;
and

in response to determining that the third electrical power provided to the load is stable:

electrically connecting the plurality of DC/AC inverters to the rectifier path by closing the circuit breaker; and

providing at least a first part of the second electrical power to the load via the rectifier path and the AC/DC rectifier.

19. The method of claim 18, further comprising:

determining whether the load demand of the load is satisfied by the second electrical power;

in response to determining that the load demand of the load is satisfied by the second electrical power:

ceasing to provide the third electrical power to the load; and

providing the second electrical power on the rectifier path to the load; and

in response to determining that the load demand of the load is not satisfied by the second electrical power, provide the second and the third electrical power on the rectifier path to the load.

20. The method of claim 11, wherein the at least one power module comprises a fuel cell module and wherein the load comprises an information technology load.

21. A fuel cell system, comprising:

a plurality of power modules each including at least one fuel cell;

a plurality of direct current (DC)/DC converters each having an input end and an output end, and each electrically connected to a power module of the plurality of power modules at the input end;

a DC power bus electrically connected to the plurality of DC/DC converters in parallel at the output end and electrically connectable to a load;

a plurality of DC/alternating current (AC) inverters each having a DC end and an AC end, and each electrically connected to a power module of the plurality of power modules at the DC end;

an AC bus electrically connected to the plurality of DC/AC inverters at the AC end in parallel;

a bidirectional DC/AC inverter having a DC end and an AC end, and electrically connected to the AC bus at the AC end;

a power storage device electrically connected to the bidirectional DC/AC inverter at the DC end; and

an AC/DC rectifier having an AC end and a DC end, and electrically connected to the AC bus at the AC end and to the DC power bus at the DC end.

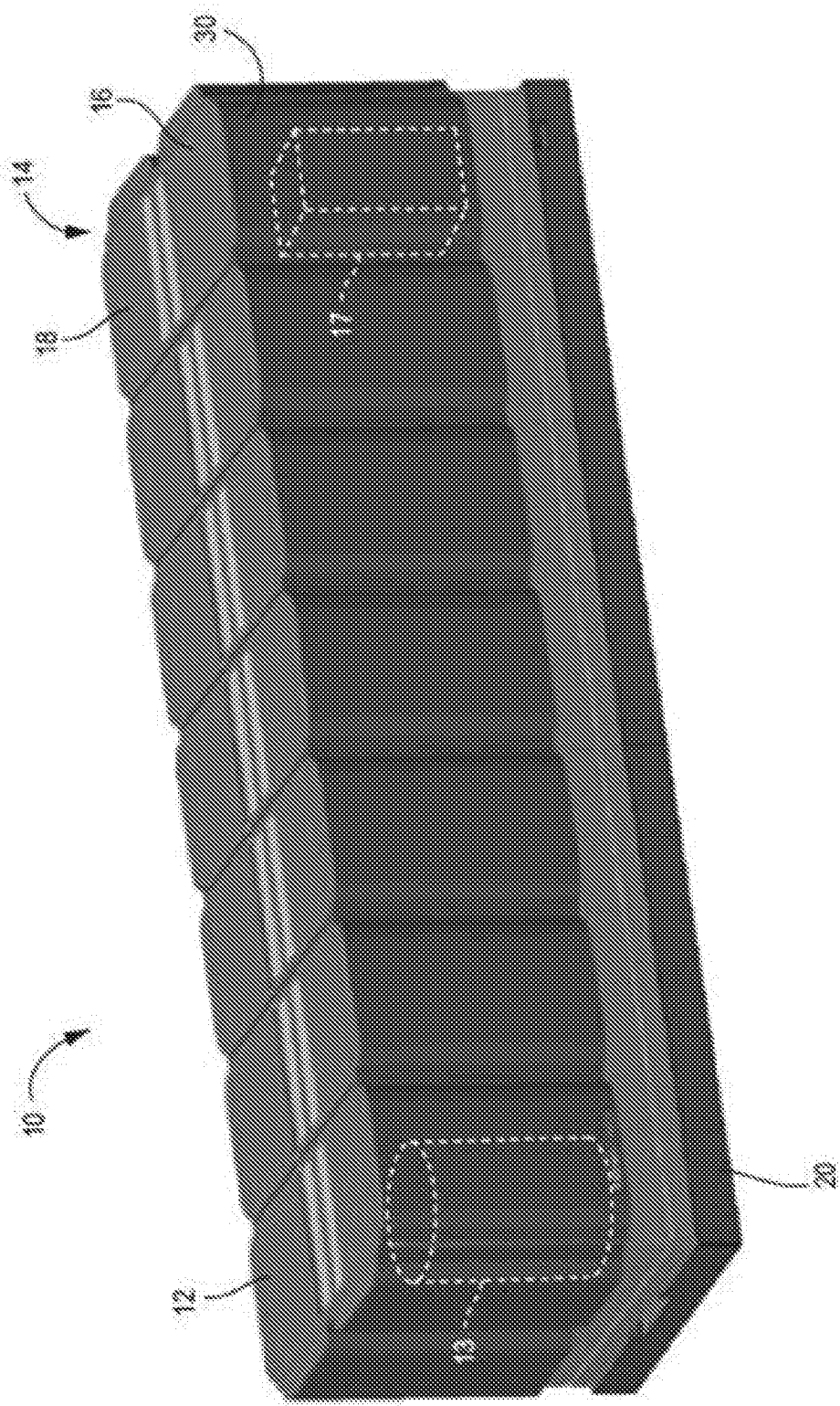
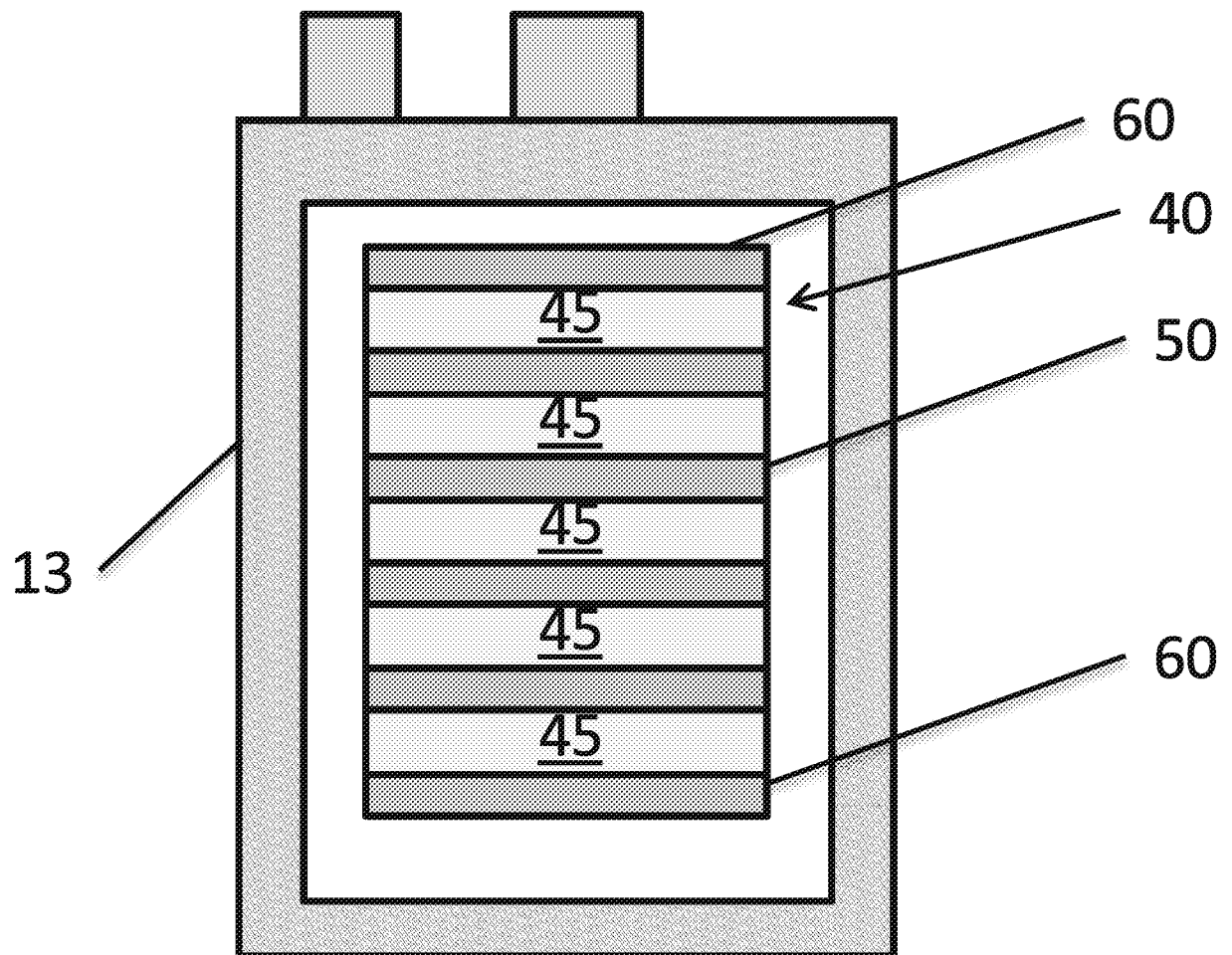


FIG. 1

**FIG. 2**

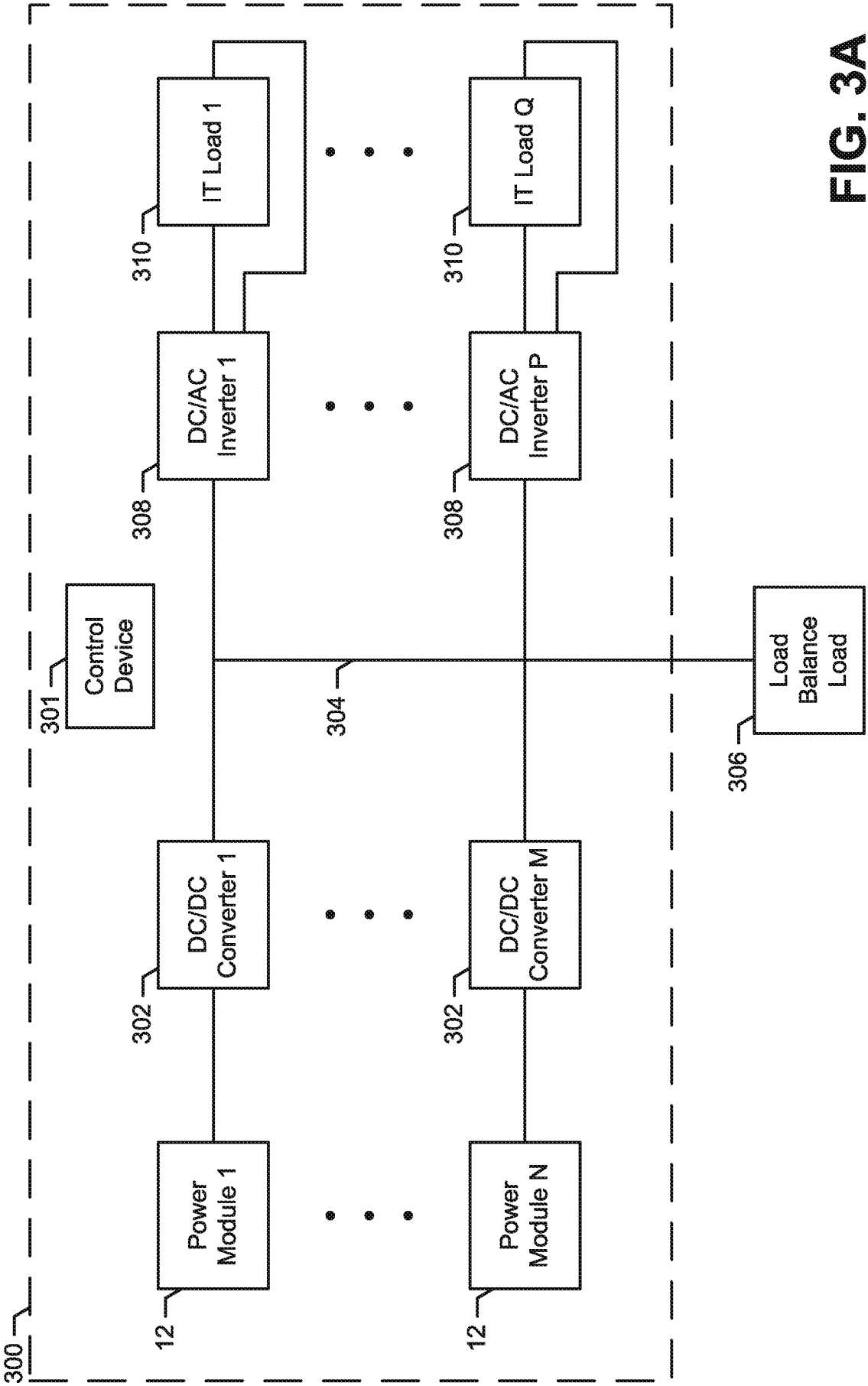


FIG. 3A

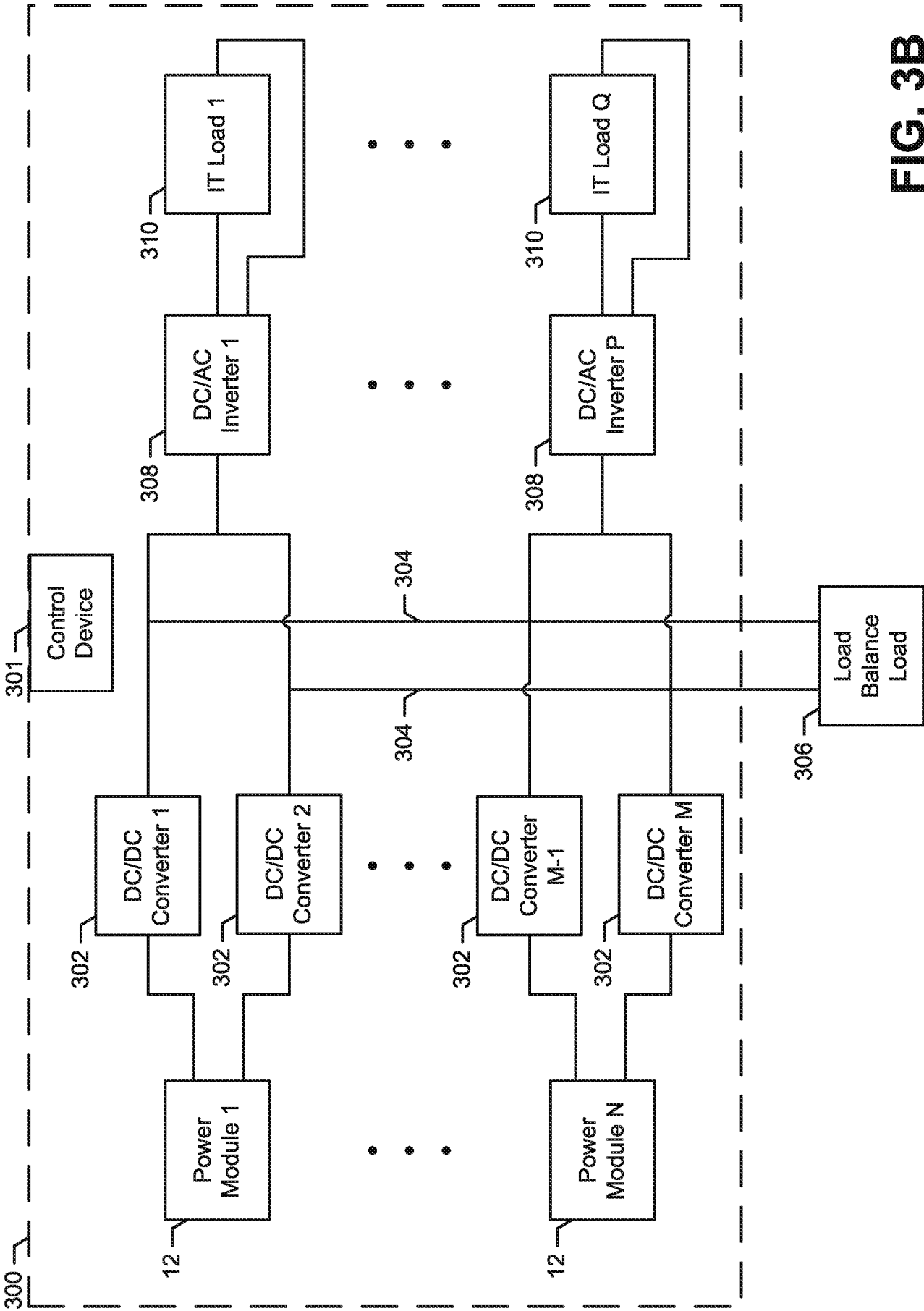


FIG. 3B

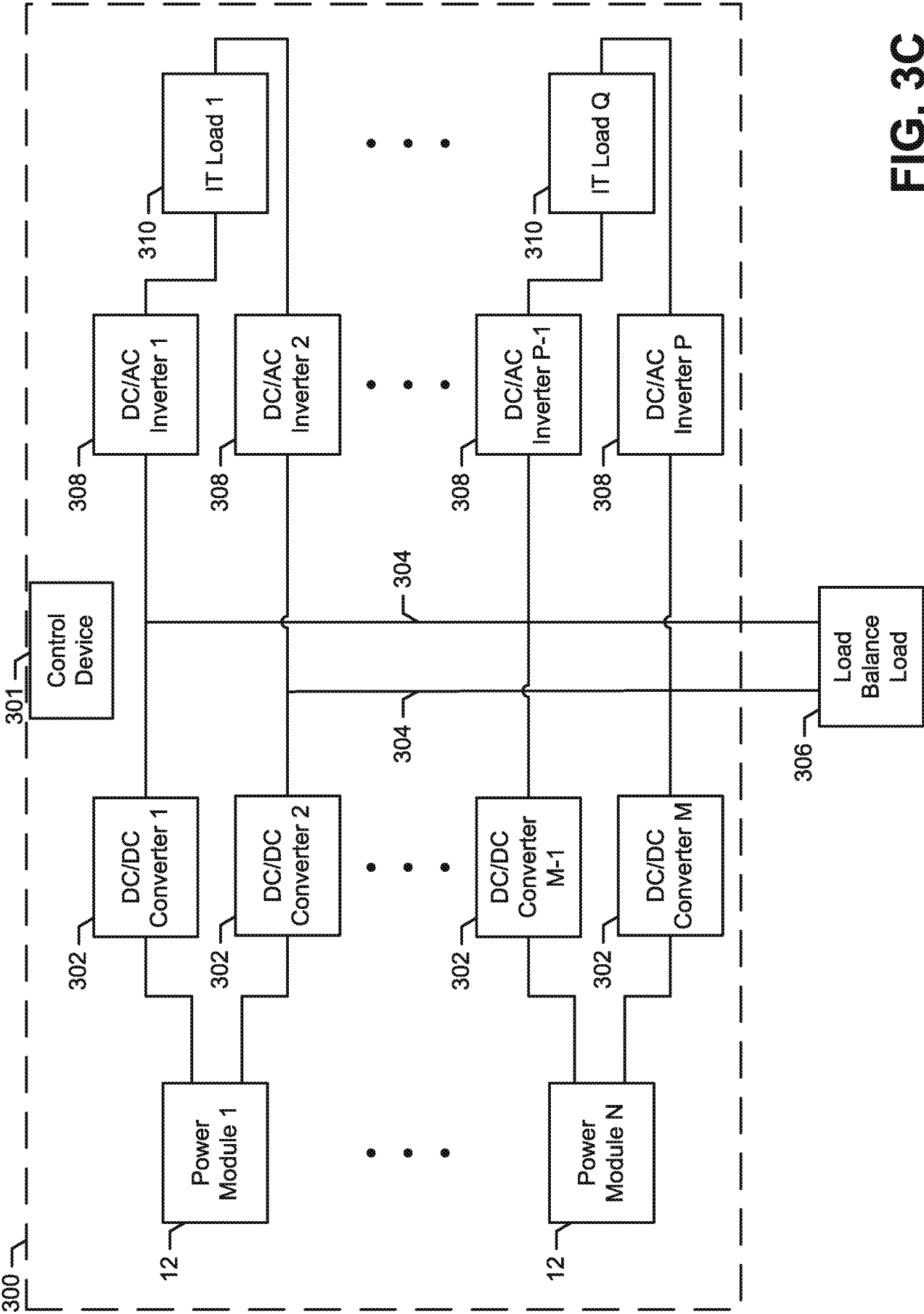


FIG. 3C

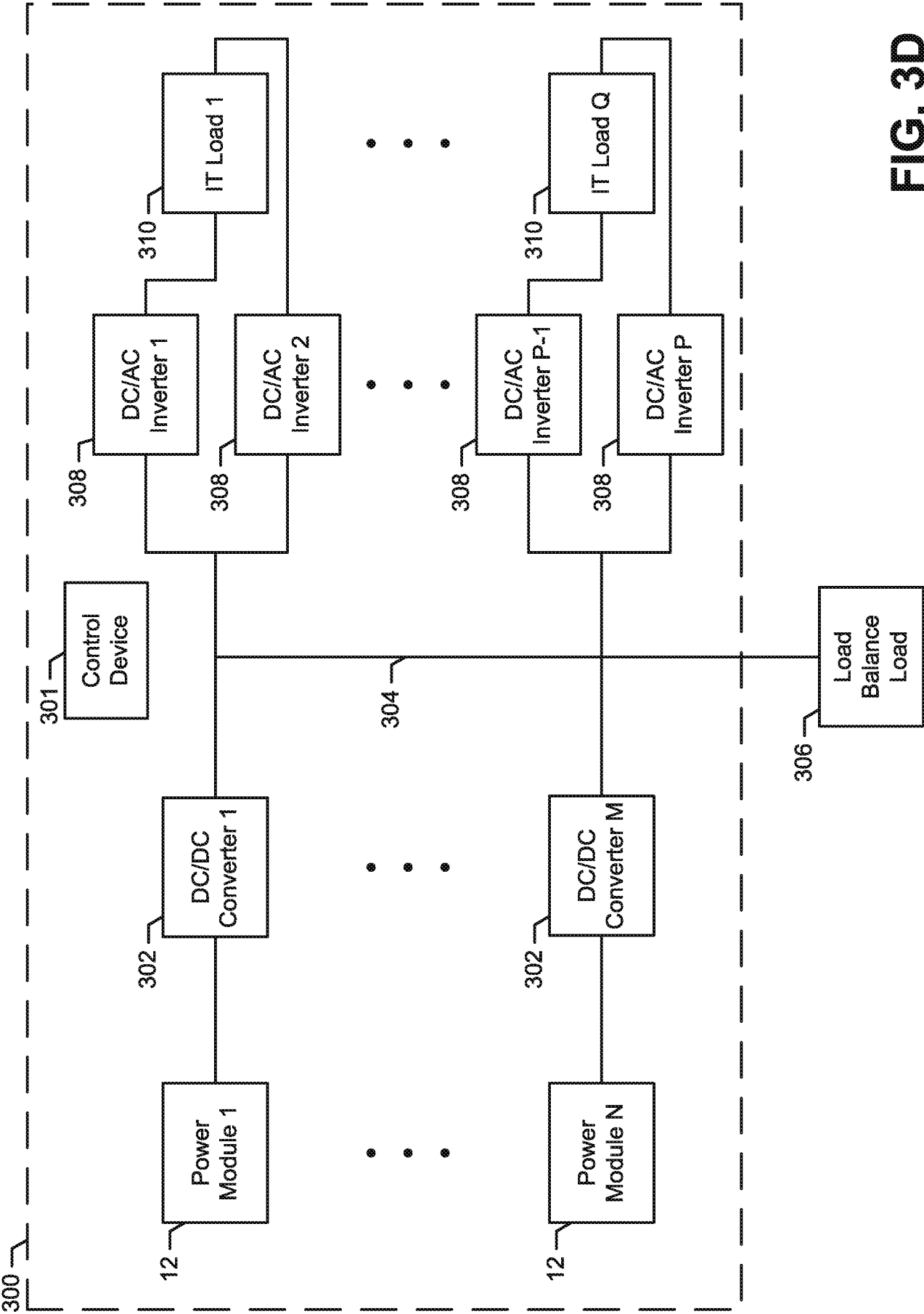


FIG. 3D

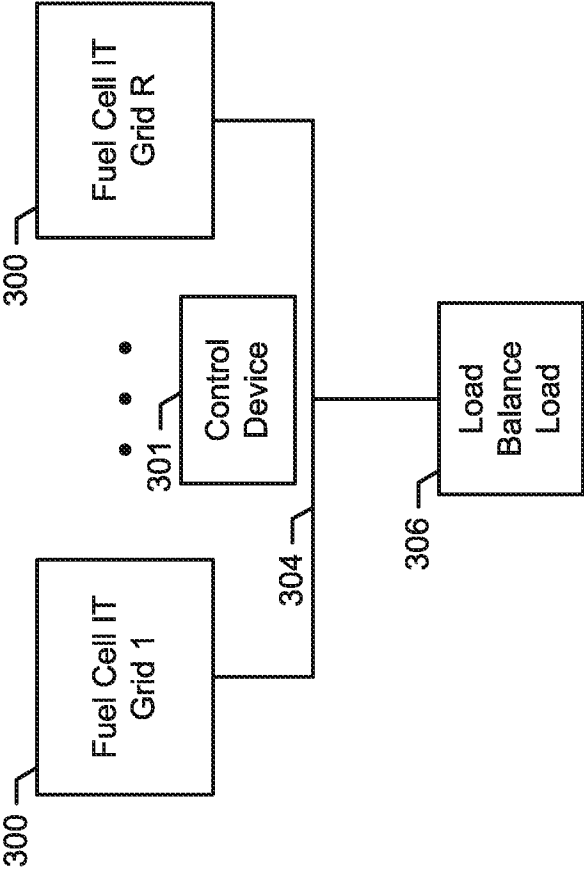


FIG. 3E

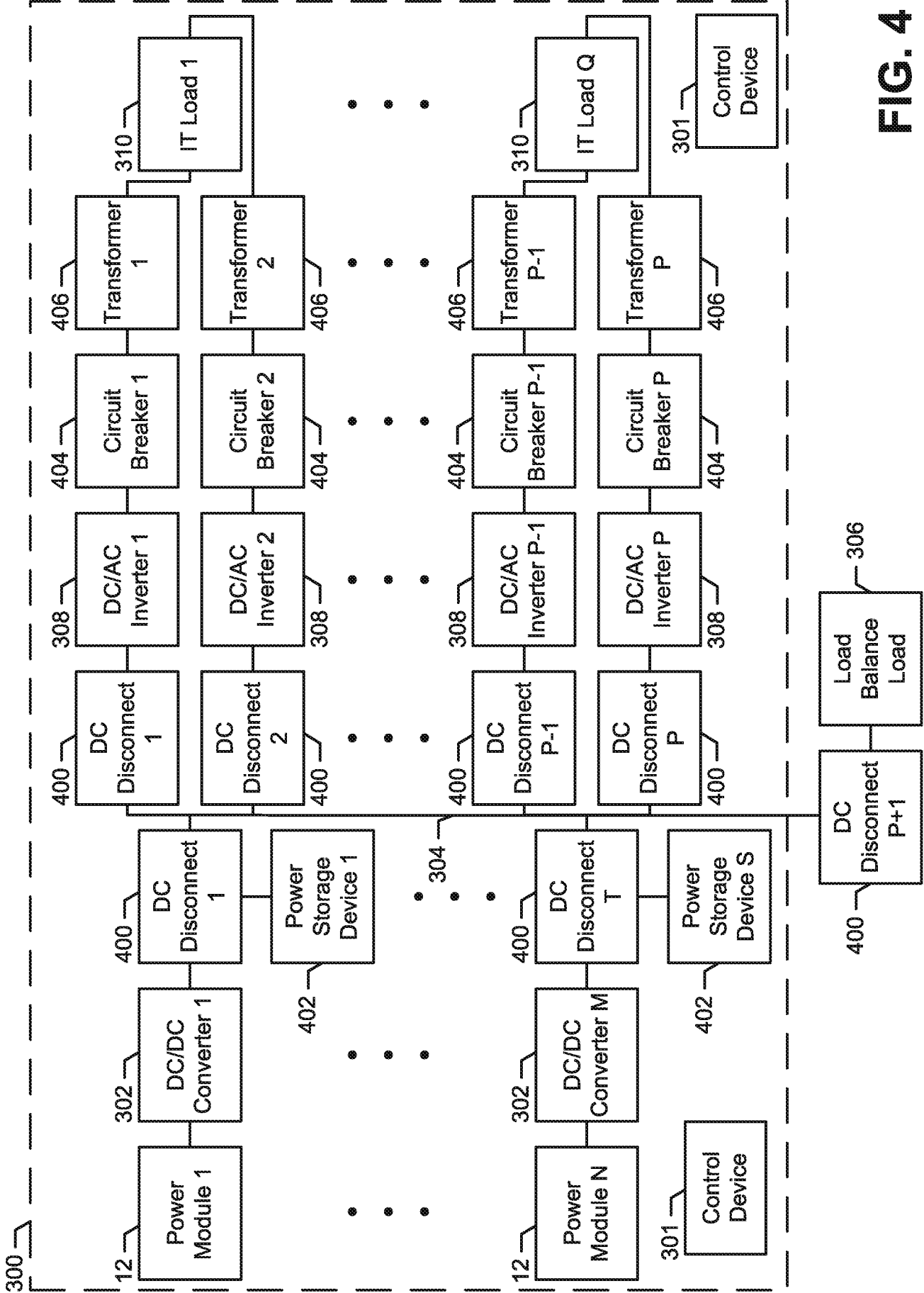
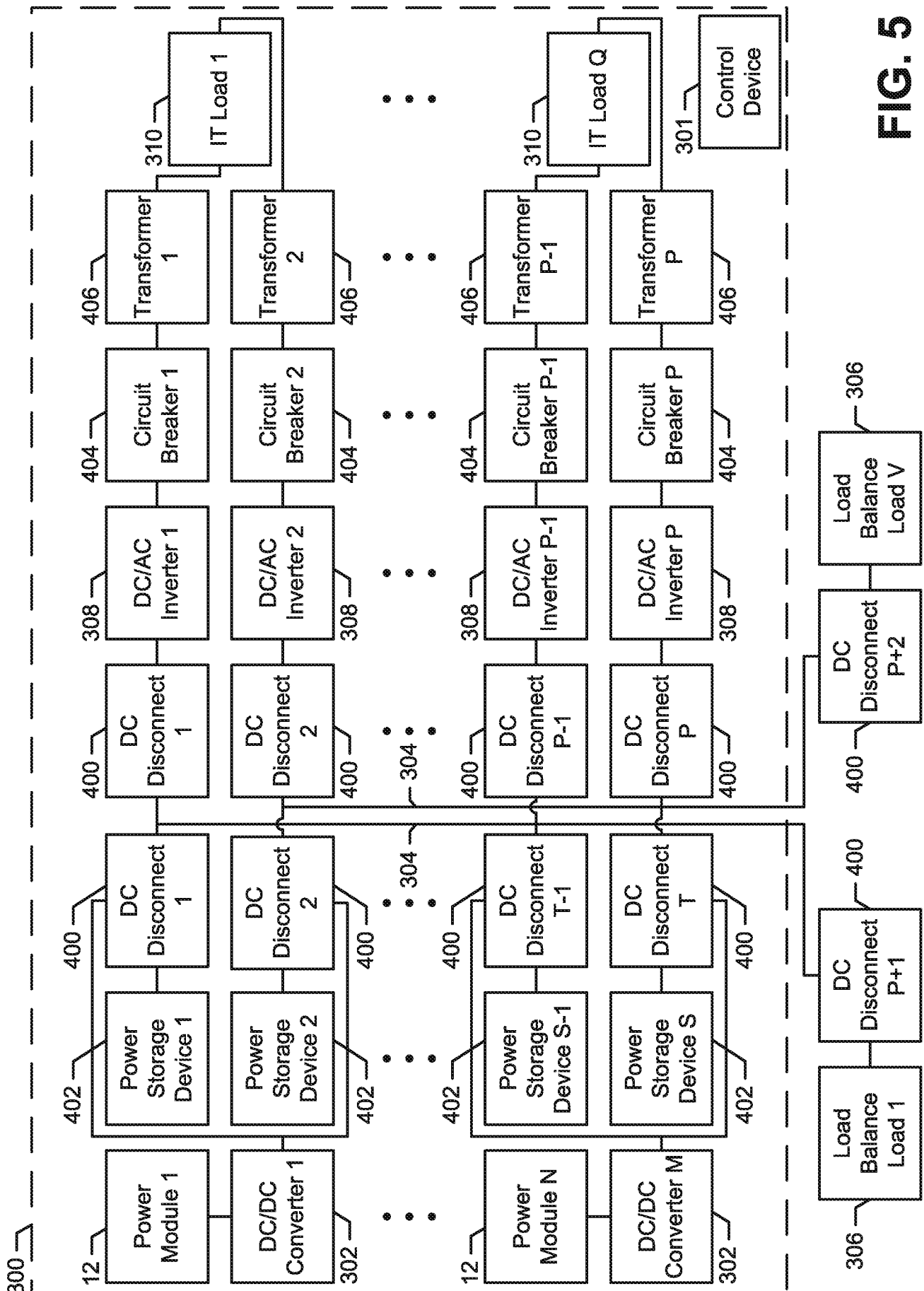


FIG. 4



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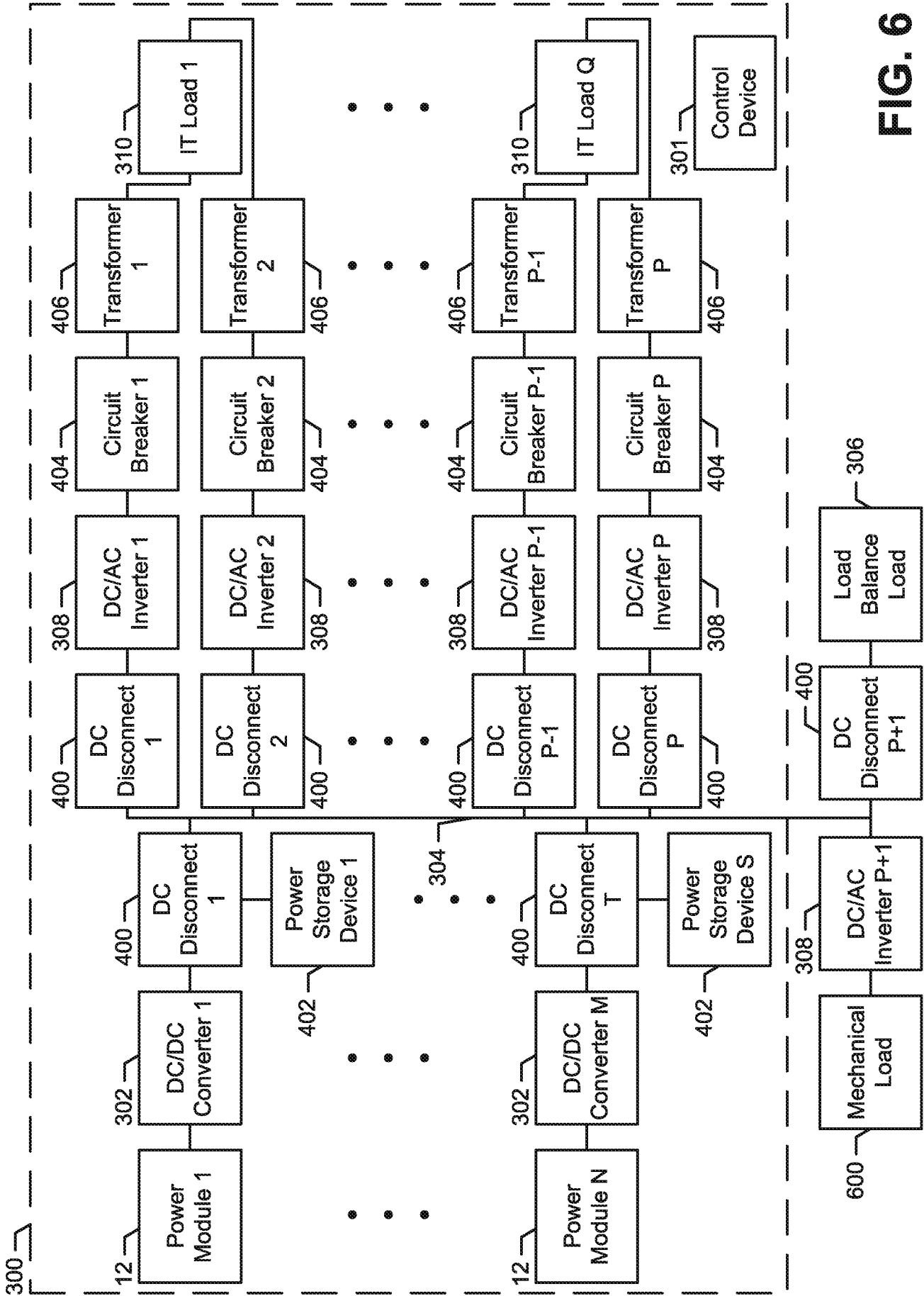
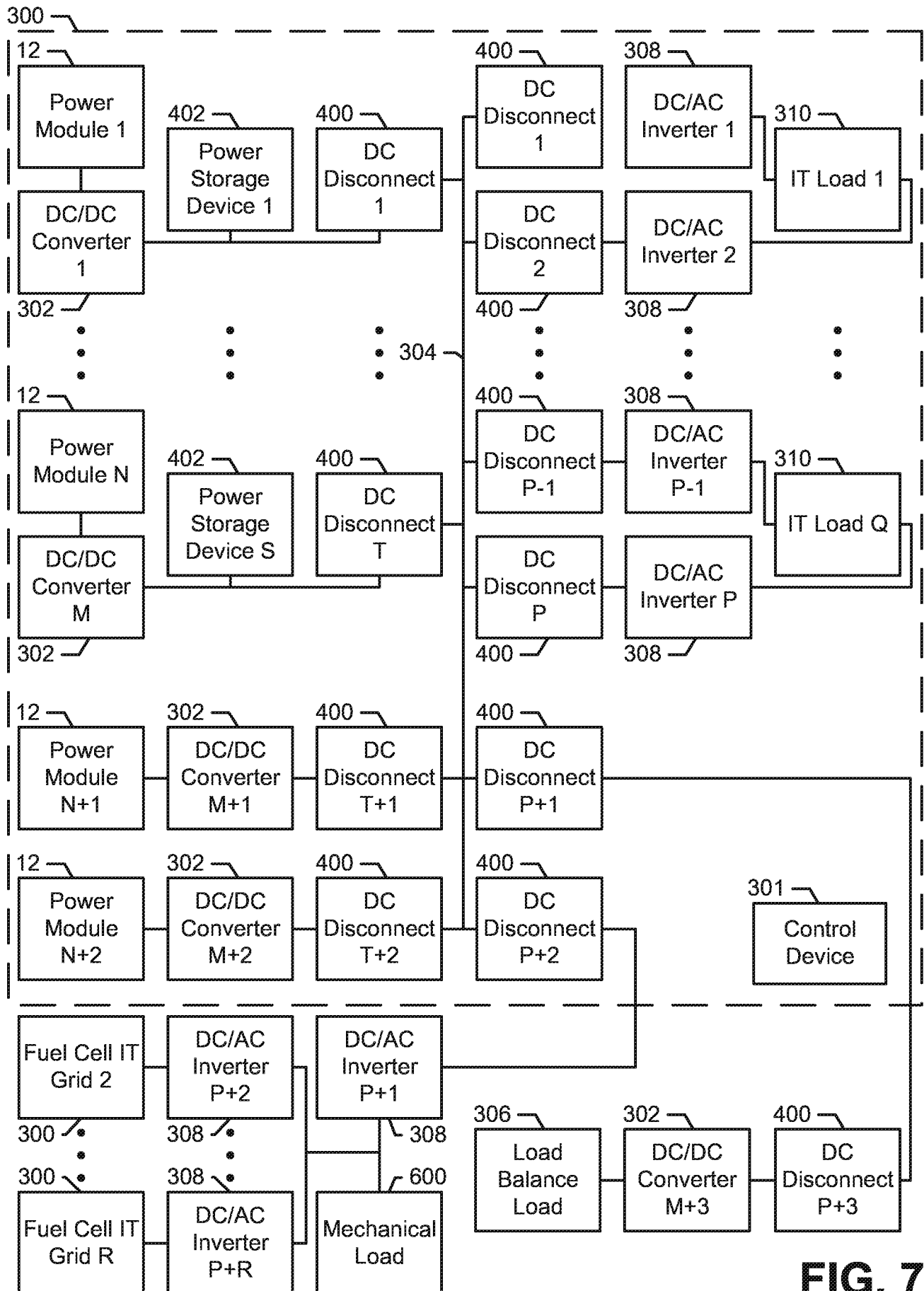
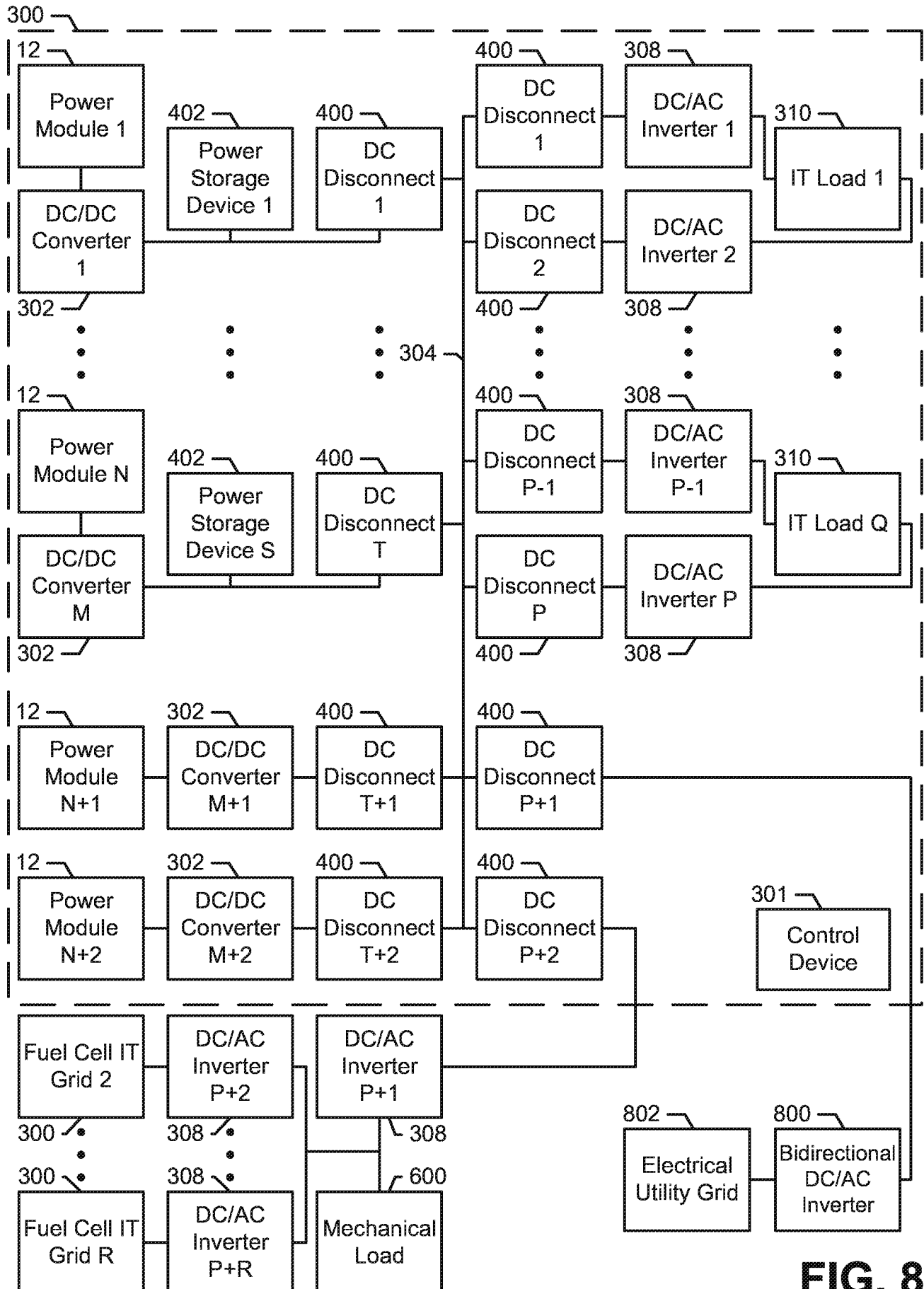
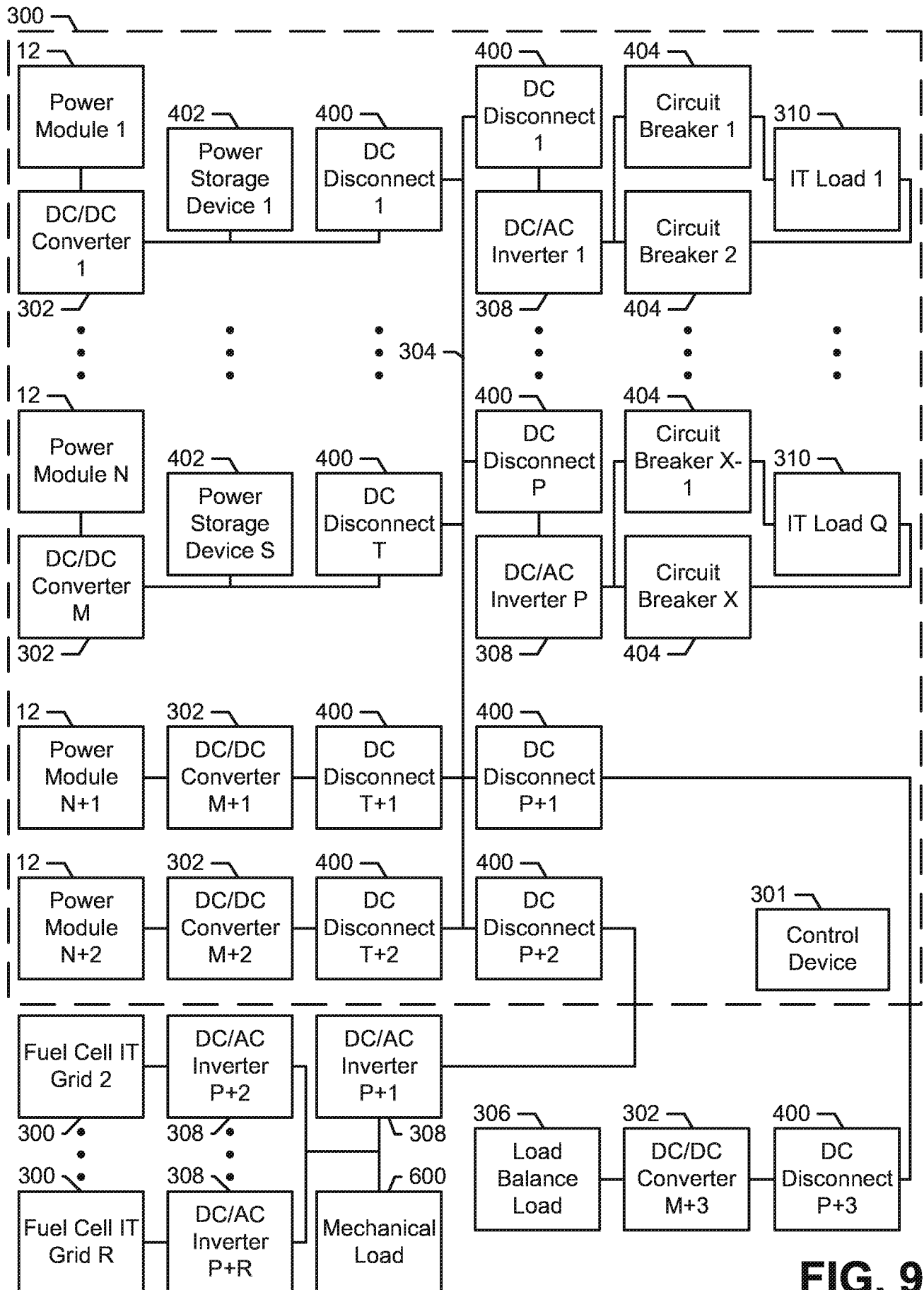
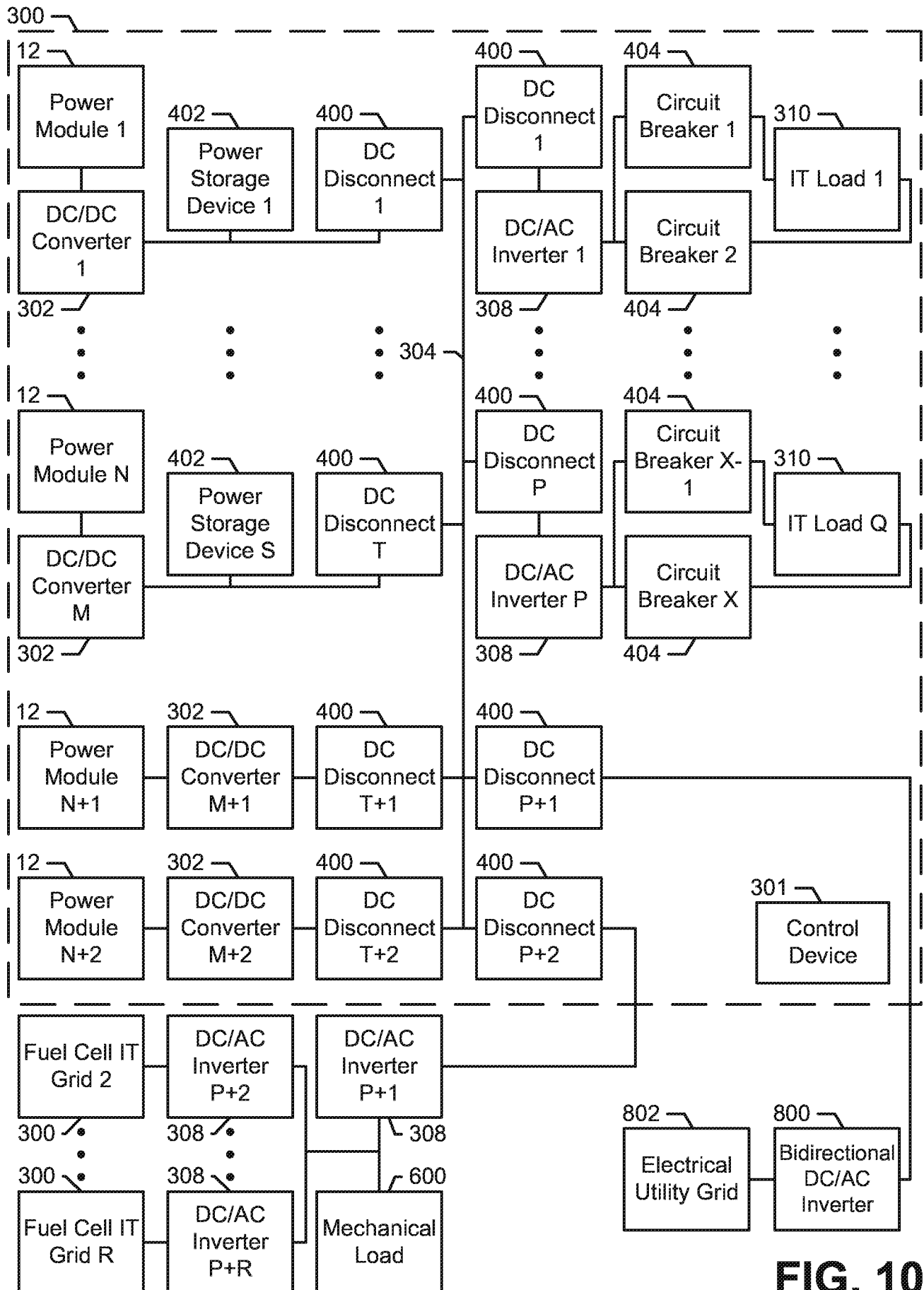


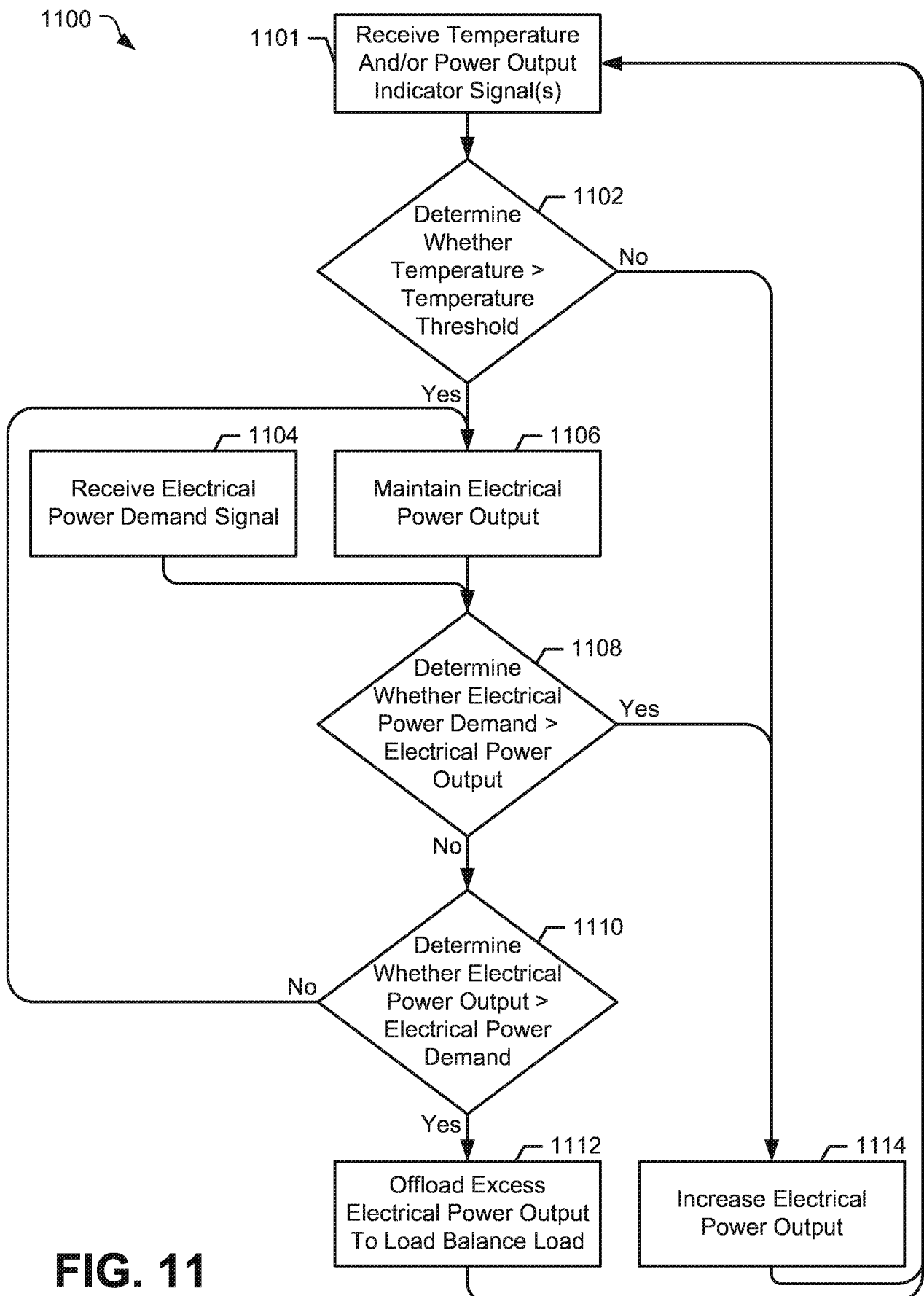
FIG. 6

**FIG. 7**



**FIG. 9**

**FIG. 10**

**FIG. 11**

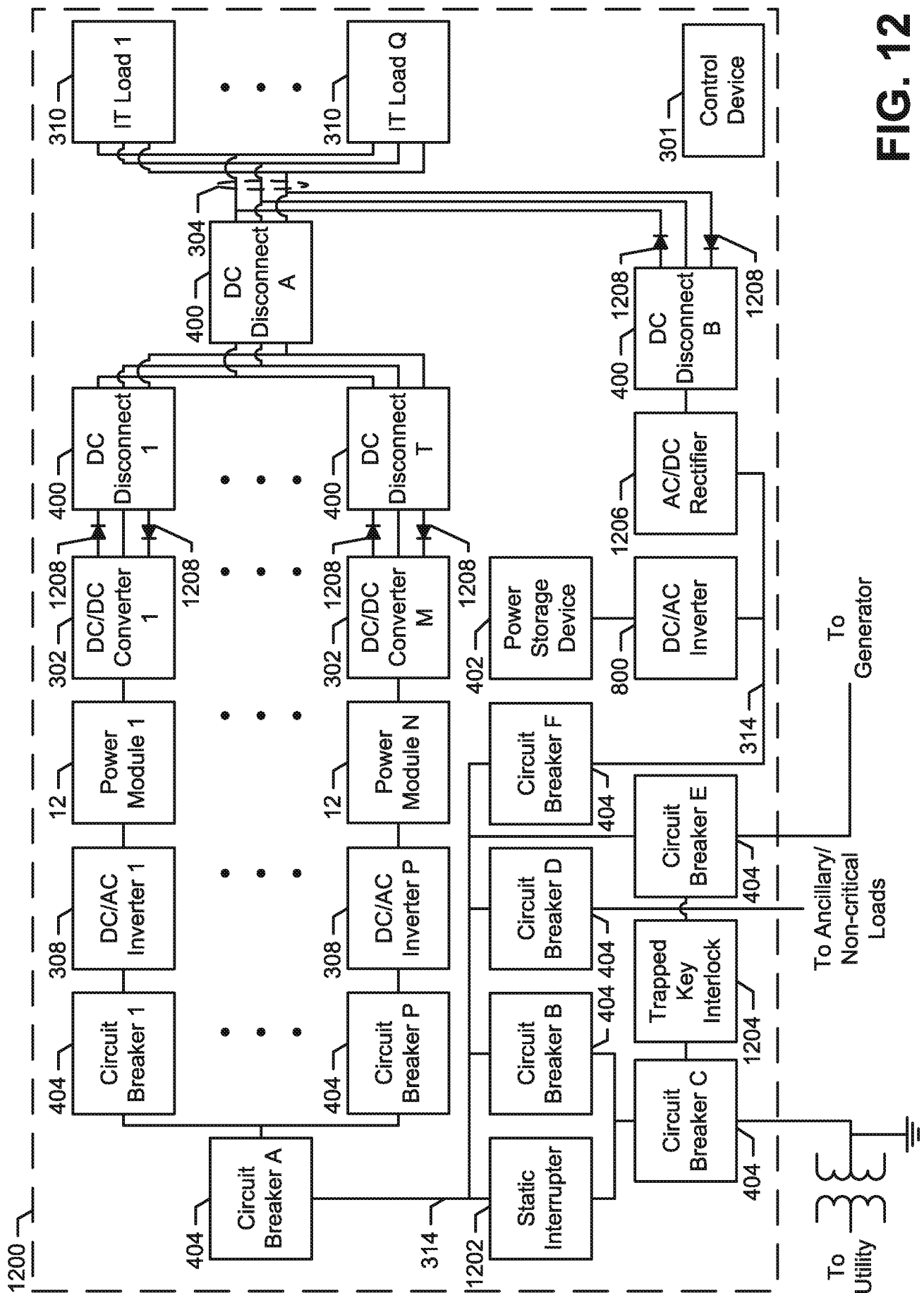


Fig. 12

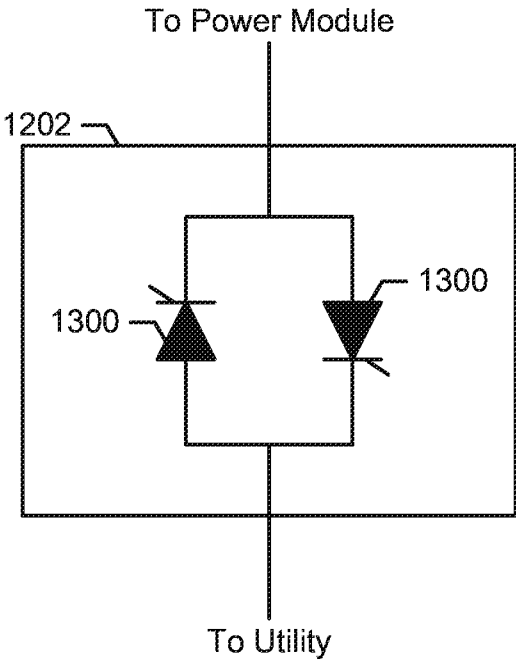
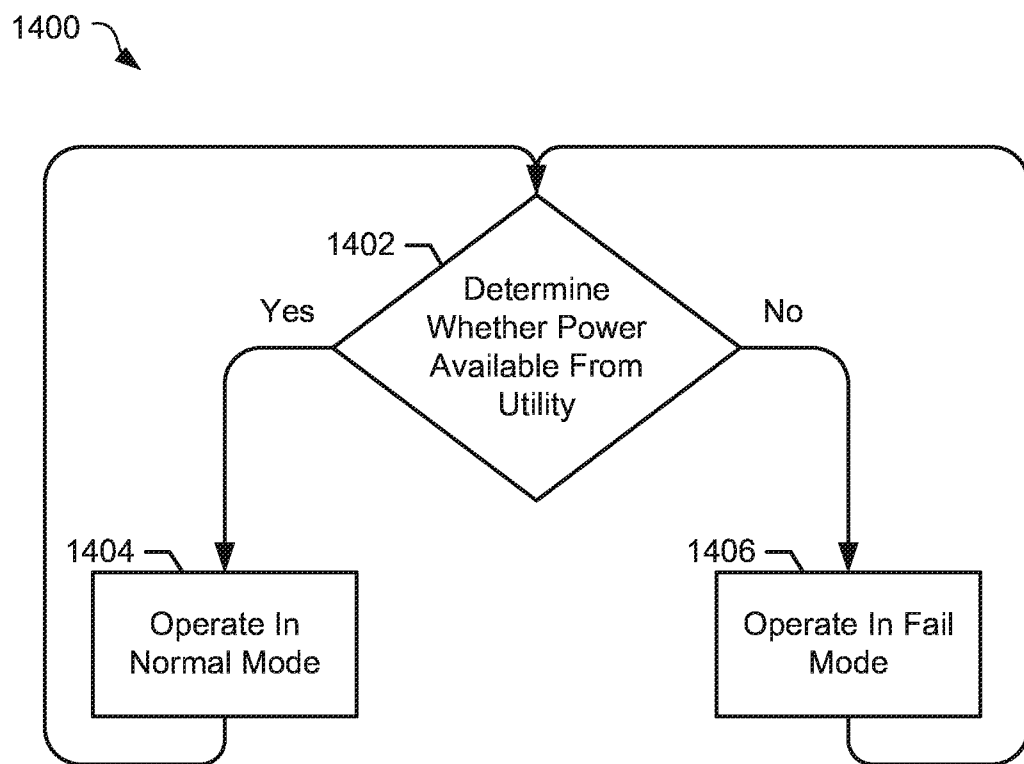
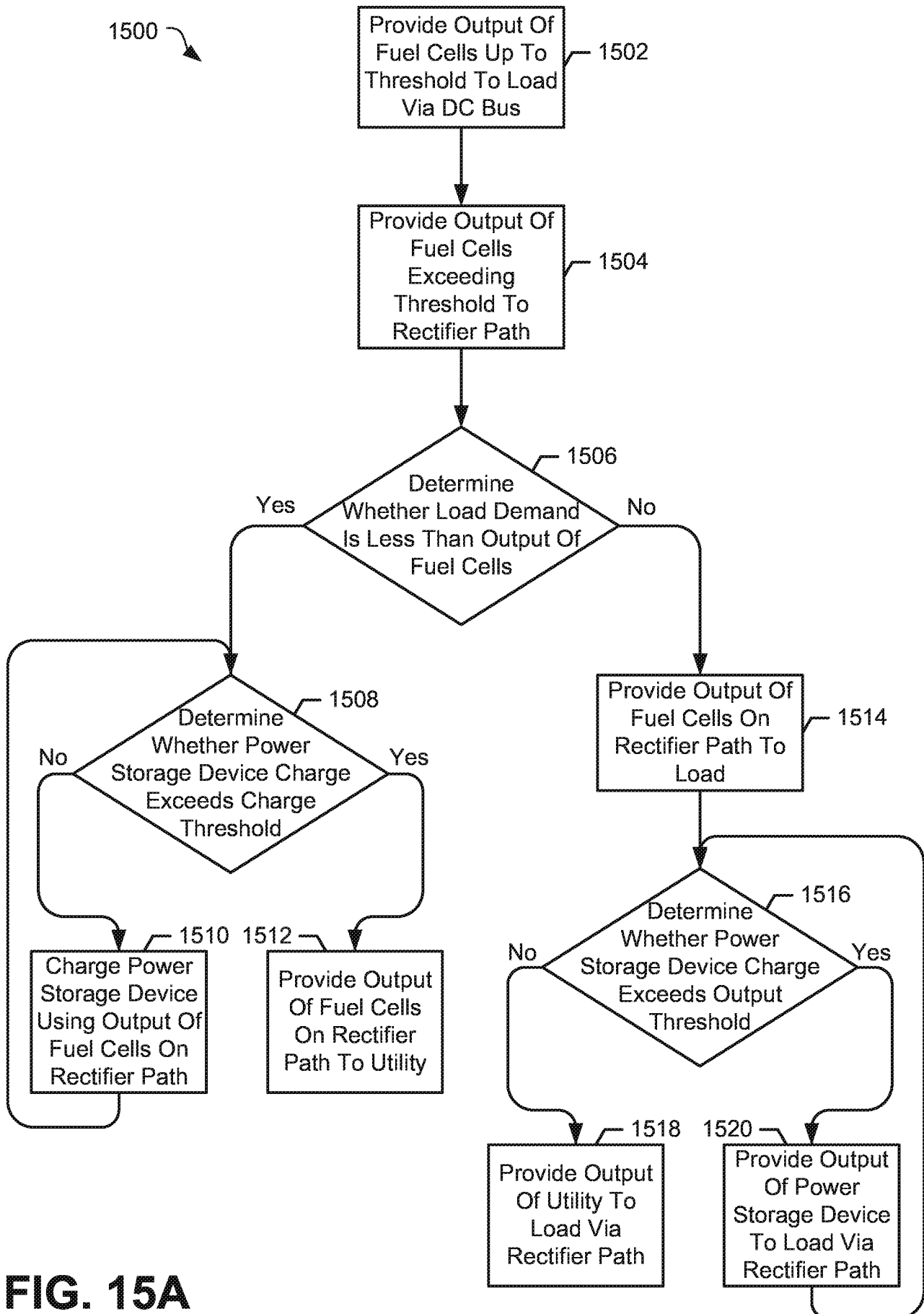
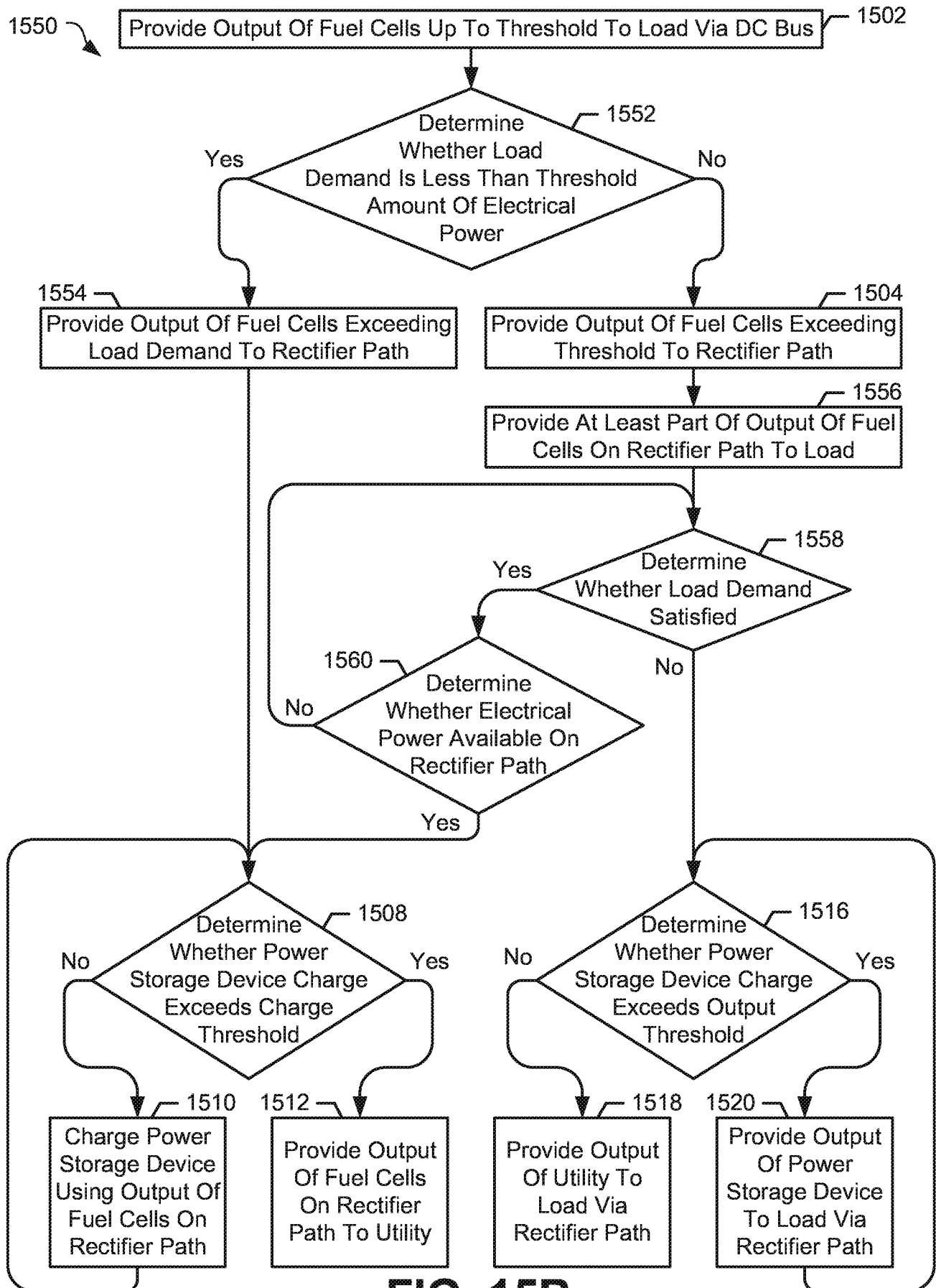


FIG. 13

**FIG. 14**



**FIG. 15B**

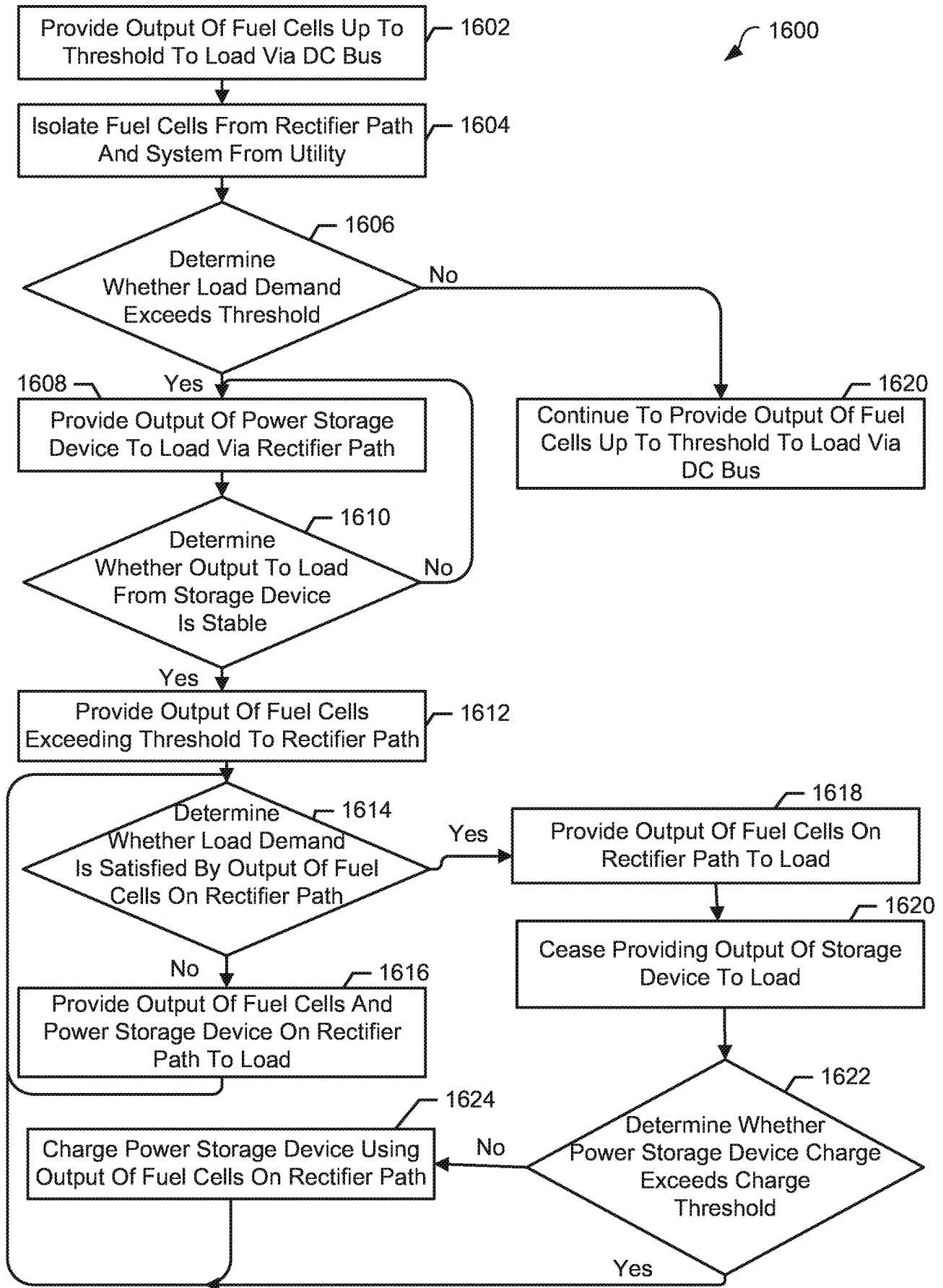


FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2020/018589**A. CLASSIFICATION OF SUBJECT MATTER****H02J 3/38(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02J 3/38; B60L 11/12; B60L 11/18; G05B 15/02; H02J 3/32; H02J 9/04; H02J 9/06; H02K 19/02; H02K 47/04; H02P 27/08

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: power-supply, excess, threshold, load-demand, rectifier

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018-0123496 A1 (EMPOWER MICRO SYSTEMS INC.) 03 May 2018 paragraphs [0035]-[0082]; claim 1; and figure 8	1-21
A	US 2017-0331325 A1 (CORITECH SERVICES, INC.) 16 November 2017 paragraphs [0016]-[0034]; claim 1; and figure 3	1-21
A	US 2018-0331611 A1 (ENERGY PRODUCING SYSTSEMS OF AMERICA L.L.C.) 15 November 2018 paragraphs [0019]-[0022]; claim 1; and figure 1	1-21
A	US 2018-0198282 A1 (CUMMINS POWER GENERATION IP, INC.) 12 July 2018 paragraphs [0025]-[0027]; claim 21; and figure 1	1-21
A	KR 10-2018-0045965 A (HYUNDAI MOTOR COMPANY et al.) 08 May 2018 paragraphs [0048]-[0060]; claim 1; and figure 1	1-21



Further documents are listed in the continuation of Box C.



See patent family annex.

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

12 June 2020 (12.06.2020)

Date of mailing of the international search report

12 June 2020 (12.06.2020)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsu-ro, Seo-gu, Daejeon, 35208, Republic of Korea



Facsimile No. +82-42-481-8578

Authorized officer

JANG, Gijeong

Telephone No. +82-42-481-8364



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2020/018589

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